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POTENTIAL FOR EXCESSIVE IGNITION DELAY AND HANGFIRE OF M203E1 PROPELLING CHARGE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This engineering study was initiated to determine the causes of excessive ignition delay and hangfire potential for the 155 mm howitzer's M203E1 propelling charge, which produced two hangfires during cold temperature testing. The primer, black powder, fabric, environment, and aging of the charge were studied as possible contributors to a hangfire.

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1. BRL testing eliminated the M82 primer as a contributor to the excessive delays or hangfires.

2. The black powder used has a relative quickness (RQ) which affects the ignition train's ingition delay. The M203 technical data package now requires that only black powder with a high RQ value, which lowers the ignition delay, be used.

3. Laboratory tests showed that the lighter weight fabrics used on the inside of the base igniter pad reduced the ignition delay. The effects were more dramatic with the slower black powder. The lighter weight fabric is not used in the M203 because it cannot survive rough handling tests.

4. Environmental tests showed that humidity and cold temperatures increased black powder's ignition time and that dry air decreased it. The data appear to confirm the postulation that the original hangfires were at least partially caused by the cold temperature, -51°C (-60°F), conditioning of charges which were manufactured and fired under conditions of high relative humidity and warm temperatures (August).

5. Complete M203E1 charges assembled with high RQ black powder in the ignition train were stored at 37.8°C (100°F) for 1 year.

These charges, which were sampled every 3 months, were cold soaked for 24 hours and then fired at -54°C (-65°F). The results of the 12-month aging showed no significant variation in ignition delay with time.

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INTRODUCTION

The M203 propelling charge was designed for use as the top zone charge for the new 155 mm M198 howitzer, and it is also being considered for use in the 155 mm M109A2/A3 extended range howitzer system. The charge is center core ignited and contains approximately 11.8 kg (26 lb) of M30A1 propellant (fig. 1).

During qualification testing of the M203 charge, several hangfires[1] were experienced. The source of this problem was believed to be multifaceted and included such influences as test conditions, and type and source of raw materials, as well as the procedures and conditions under which the charges were loaded, assembled, and packed.

An interim solution evolved when it was discovered that the inventory of black powder contained lots which, when tested against a reference, had low relative quickness (RQ) values[2]. This condition was found to be prevalent in the black powder lots furnished by Canadian Industries Limited. On the other hand, black powder lots furnished by Gearhart-Owens were found to be quicker.

The interim solution was a change in the M203 propelling charge technical data package (TDP) that requires the use of black powder having a minimum RQ of 92%.

BACKGROUND

In August 1977 two hangfires of 7.6- and 6.3-second duration occurred at Jefferson Proving Ground (JPG) with the M203 propelling charge (loaded with CIL-7-11 black powder) conditioned to -51°C (-60°F). At BRL a third hangfire occurred in September 1977 (with the same CIL-7-11 black powder) during special ballistic tests designed to reproduce the problem. All three hangfires occurred with the charge located in the maximum forward position in the M199 cannon, during the firing of the M549 projectile.

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[1]A hangfire can be defined as a delay in the ignition of the propelling charge which is perceptible to the human ear.

[2]Quickness is the slope of a portion of a pressure-time curve generated by a fixed quantity of powder ignited under controlled conditions in a closed bomb.

In addition to the hangfires, longer ignition delays were noted with the charge in the normal and maximum standoff positions than had been experienced in any other tests conducted during the preceeding 2-year period.

An investigation was performed by ARRADCOM (LCWSL and BRL) from September to November 1977. It provided preliminary data on the significance of standoff, snake gap, and black powder type. Laboratory and ballistic tests showed that a switch to Gearhart-Owens black powder could reduce the ignition delay sufficiently to eliminate the hangfire problem.

Available project funds were then committed to a test plan intended to confirm the satisfactory performance of the M203E1 propelling charge with Gearhart-Owens black powder. Ballistic testing was done in sufficient time to enable M203 propelling charge production, planned for spring of 1978, to have the benefit of the preferred black powder.

Although the preferred testing led to the use of Gearhart-Owens black powder in order to achieve shorter ignition delays, this study was initiated to gain a better insight into the ignition delay/hangfire problem and to ascertain whether or not there were other causes for the hangfires.

DISCUSSION

The first course of action was to release the M203 charge for production. From past experience, black powder manufactured by Canadian Industries Limited (CIL) had relative quickness values significantly less than that manufactured by Gearhart-Owens (GOE). A series of tests were performed which compared the RQ values of various lots of black powder on hand. Data shown in table 1 confirmed the difference.

The TDP was changed to require black powder with an RQ greater than 92%. GOE black powder met this requirement, and the M203E1 propelling charges were thus produced.

The second course of action was to initiate, plan, and fund this study. To determine the hangfire potential of the M203 propelling charge. There were five areas which were studied: (1) primer, (2) black powder, (3) fabric, (4) environment, and (5) aging.

M82 Primer Study

During the hangfire investigation, BRL fired 90 test rounds. They were able to generate one hangfire. They also happened to use two different lots of M82 primers. To determine whether or not the primer contributed to the hangfire, the pressure generated in the spindle flash hole was measured as a function of time and was integrated from 0 to 10 milliseconds. The area under the pressure-time (P-T) curve thus generated by the two lots of primers was as follows:

Lot	Area under P-T curve
Lot LS 159-37	29.07 MPa ms or 4220 psi
Lot LS 159-92	28.19 MPa ms or 4090 psi

The difference in area was insignificant; therefore, it was concluded that the M82 primer had no effect on the ballistic test results (ref 1).

Black Powder Study

The black powder (BP) stocks at Indiana AAP were produced by four different manufacturers: Austin, Dupont, GOE, and CIL. Most of the stock is CIL or GOE. BP made by CIL was used in the ignition train of the M203s in which the hangfire occurred.

Tests conducted on lots of GOE and CIL black powder showed that both lots fall within the composition and granulation requirements (table 2); however, closed bomb data on relative quickness, ignition delay, and burn time showed that the GOE BP was faster burning than the CIL BP. Additional RQ tests were conducted on nine samples of GOE BP and on four samples of CIL BP. In all cases the RQ values were higher (quicker) for the GOE BP than for the CIL BP (table 1). RQ values for the four CIL lots ranged from 88% to 100%, while the nine GOE lots ranged from 108% to 163% RQ. Obviously there is a definite lot-to-lot variation in RQ, and as the RQ values increase, the igniton delay time decreases. This fact was demonstrated by gun firings at JPG (ref 2 and table 3 and tests in the ARRADCOM simulator (ref 3).

In the ARRADCOM simulator firings M203E1 charges were assembled with two lots of BP assembled in the base pad and snake. One lot of BP (GOE-75-2) had an RQ of 108 (slow) and the other lot (GOE-75-61) had an RQ of 163 (fast). The charges were conditioned and fired at -54°C (-65°F) at standoffs of 25.4 and 54 mm [1 and 2 1/8 inches (table 4)].

Fabric Study

The base pad, which contains the black powder, is made up of two layers of cloth. The back layer, which contacts the snake and propellant, is made from cloth weighing between .2289 and .2458 kg per M^2 (6.75 and 7.25 oz per yd^2). To assess the effect of reducing the weight of the the front layer of cloth to a value between .0949 and 0.1085 kg per M^2 (2.8 and 3.2 oz per yd^2) base igniter loading assemblies were fabricated using fast (RQ 163) and slow (RQ 108) black powder. Four groups of base igniter assemblies were thus available for testing:

Group	Cloth type	RQ
M1	Standard	fast
M2	Standard	slow
P1	Thin	fast
P2	Thin	slow

The base igniter assemblies were conditioned at -55°C (-67°F) for 24 hours minimum and fired at 25.4 mm (1 in.) standoff in the ARRADCOM 155mm ballistic simulator (described in JANNAF papers presented in 1973 and 1974). In short, the simulator represents a 155mm cannon chamber. The chamber is filled with aluminum rods 12.7 mm in diameter by 25.4 mm long (1/2 in. dia by 1 in. long). The base igniter assembly--consisting of the base pad, snake, and nitrocellulose (NC) tube--was embedded in the chamber with the aluminum rods. Fifteen multiperforated live grains of M30A1 propellant (RAD E-72-2) were wrapped approximately halfway down the nitrocellulose tube with a rubber band. An M82 primer ignited the base pad, which in turn ignited the snake. The burning snake ignited the M30A1 propellant. The burning propellant and black powder pressurized the chamber. The speed of ignition by the M82 primer was due to the variation in cloth; and this speed was the measure used to evaluate the different cloths.

The simulator was positioned in a wooden frame and was enveloped with dry ice to maintain the low temperture.

These data were obtained in digital form with a Biomotion model 1015. Sampling times were 0.1 milliseconds per reading.

The test results are shown in table 5 and figure 2. The fast BP reached the designated pressures in less time than the slow burning BP and that the thin cloth expedites the attainment of the designated pressures with the slow BP (P2 vs M2). With the fast BP the type of cloth (P1 vs M1) has only a marginal effect on the time needed to achieve the designated pressure.

Another way to represent these data is in terms of the time required for specific events in the ignition and burning process to occur. The events selected are initiation of the base pad, maximum rate of pressure rise due to core burning, and initiation of the propellant. With data shown in this manner, it is evident that the lighter weight fabric still tends to give shorter times, but that the more significant factor is the burning property of the black powder (table 6).

During the preliminary firings, the propellant grains were placed in a standard base pad midway in the charge; they were not tied to the NC tube, completely exposed, as in the described experiments. One firing was made from each of the four groups (P1, P2, M1, M2). The propellant ignited only under the P1 condition, i.e., thin cloth, fast BP. In all other instances the cloth was singed, and the propellant could not be ignited. As a consequence, all subsequent experiments were conducted as described with M30A1 grains tied to the NC tube with a rubber band.

With the thinner cloth the charge will not survive rough handling; therefore, it is not considered an acceptable option for reducing ignition delay.

Aging Study

Background

It was believed that hangfires may be due to a transfer of moisture between the energetic materials and the inert materials (including packaging) of the charge during storage. The aging study was expected to disclose the validity of this postulation.

A total of 196 M203E1 propelling charge (IND Lot 78F001S017) were stored in their hermetically sealed metal containers, in a temperature environment of 37.8°C (100°F), for 1 year. At seven prescribed intervals (after 1/4, 1/2, 1, 3, 6, 9 and 12 months of storage) 28 charges were withdrawn from hot storage. Twenty-five of these charges were then wrapped in plastic bags and placed in cold storage, -54°C (-65°F), for a minimum of 24 hours. Those charges were then removed from cold storage, unwrapped, and fired. The charges were fired at maximum standoff with the M549 projectile (rocket off) from the M199 cannon (tube 73). The average ignition delay per firing is shown in table 7.

All firings from the 1/4 through 12-month storage period show higher values than those with the 0-month storage value of 79 milliseconds. However, progressive increases in ignition time with storage time is not evident.

The remaining three charges left over from each 28-charge group were subjected to a teardown inspection. The BP in the base pad and in the snake were tested separately for RQ but were combined for moisture content determination. Data for lot GOE-75-24 are shown in table 8.

Within the first 2 weeks, the moisture content of the BP increased from roughly 0.5% to 0.8%, and then it remained essentially level for the balance of the 1 year storage. Within experimental error, there is no change in the RQ values over the 12-month test period.

Total moisture and total volatiles for the M30A1 propellant were also determined. These data are shown in table 9.

Since M203 propelling charges are stored in hermetically sealed metal containers, any change in moisture content of materials in the container had to be due to an interchange between the materials. Initially all of the materials in the containers were checked for percent moisture loss. These data are shown in table 10. All of the items in the container except the propellant gained moisture over the 1-year storage. Table 11 shows some of the components, their weights, and their moisture content.

The weight loss (20.2 g) of the propellant was almost equal (within experimental error) to the weight gained (23.6 g) by the remaining paraphernalia in the container.

The black powder did not gain as much water as originally predicted, nor was there much change in the ignition delay time over the 1-year period.

Table 12 is a summary of the accumulated ballistic data, i.e., velocity pressure, differential pressure and ignition delay.

A correlation appears to exist among gun wear (apps A and B), muzzle velocity, and average pressure (table 12). Velocity gradually decreased from 797.66 meters per second (2617 fps) at 1/4 month to 787.3 meters per second (2583 fps) for the sixth and 786.6 meters per second (2581 fps) for the twelfth month. [Although the velocity for the ninth month of 794 meters per second (2605 fps) is higher than either the sixth or twelfth month values, this result is attributed to the fact that a new tube (No. 27480) in which only 27 rounds had been fired, was used for the ninth month test, whereas for the remainder of the firings tube 73 was used.]

This new tube also appeared to affect the average pressure for the ninth month [301,379 kPa (43700 psi)], which is higher than either the sixth month pressure [293,103 kPa (42500 psi)] or the twelfth month pressure [295,862 kPa (42900 psi)].

The average values for chamber pressure (copper), differential pressure, muzzle velocity, and ignition delay were checked on seven occasions to determine if they were under statistical control. These data are of interest in that they provide a ready reference of how a year's storage (aging) at elevated temperatures affects the performance of the M203E1 charge. Relative to this study the interest was in determining whether those characteristics are under statistical control during the hangfire/ignition delay program. The formulas used to check values for each M203E1 propelling charge characteristic for statistical control came from reference 4. The calculations are shown in appendixes C, D, E and F.

Pressure

The upper control limit (UCLX) calculated is 300,152 kPa (43,522 psi).

The third month arithmetic mean is 288,276 kPa (41,800 psi) which is below the lower control limit (LCLX) value of 290,483 kPa (42,120 psi). This value was the only point to fall outside the above control limits.

The upper and lower control limits for the standard deviation of the average pressures are 7,103 kPa (1,030 psi) and 455 kPa (66 psi) respectively (app D). The standard deviation of the average pressures is within the above control limits.

Ignition Delay

The upper control limit calculated for the arithmetic mean of the delay is 107 milliseconds. The lower control limit calculated is 77 milliseconds. The highest and the lowest average ignition delays from this ignition delay/hangfire program are 101 and 79 milliseconds, respectively, which are within upper and lower control limits.

Finally, the upper and lower control limits for the standard deviations are 21 and 1.4, respectively. The standard deviations for the seven monitoring occasions fall within the upper and the lower control limits for the standard deviations (app E).

Differential Pressure

The upper control limit calculated for the arithmetic mean of the differential pressure is 4,731 kPa (686 psi). The lower control limit calculated was zero. The arithmetic means for the seven occasions for this program fall within the above control limits.

Finally, the upper and lower control limits for the standard deviation of the differential pressure are 4,538 kPa (658 psi) and 290 kPa (42 psi) respectively. The standard deviations for the seven occasions fall within the upper and lower control limits for the standard deviations (app F).

The maximum individual differential pressure for cold firings [when the M203E1 charge is fired at temperatures close to -54°C (-65°F)] according to the M203 specification MIL-C-48243C is 20,690 kPa (3000 psi). The upper control limit value of 4,538 kPa (658 psi) for this program compares favorably to this value.

Velocity

The upper and lower control limits for the arithmetic mean of the average muzzle velocity are 79,461 and 78,913 meters per second (2,607 and 2,589 fps), respectively. The following average velocities fell outside these control limits:

Storage period	Average velocity mps (fps)
1/4 month (initial)	79,766 (2,617)
sixth month	78,730 (2,583)
twelfth month	78,669 (2,581)

The upper and lower control limits for the standard deviations of the velocity are 3.96 meters per second and 0.3 meters per second respectively. The standard deviations for the seven monitoring occasions fall within these limits (app C).

Environmental Study

The basis for this effort is essentially that the two hangfires experienced in August 1977 occurred during a test requiring the propelling charge be conditioned to and fired at -51°C (60°F).- While proving grounds take care to minimize the time period between removal from the cold box and firing, it is not possible to prevent frosting and condensation on the charge. This is commonly seen on all munitions tested in this manner but perhaps is more significant on separate loaded charges where there is no cartridge case or metal primer to limit the contact of cold energetic components to warm air. Thus, the speculation is that condensation on igniter components caused the hangfires and, further, that there was no real design or quality problem since the test method represents an unreal or artificial condition. There is further speculation that handling of charges in preparation for the test also could have contributed to the hangfires. There is exposure of energetic materials during weighing, inspection, and other test preparations during which moistures and volatiles could be gained or lost. Repacking in the charge container for conditioning in the cold box then gives another synthetic aspect to the testing procedure.

The purpose of the environmental subtask was to attempt to quantify the artificial aspect and determine whether or not this represents a possible cause for long ignition delays or hangfires. The ARRADCOM simulator which simulates the 155 mm howitzer chamber, was used to evaluate fabric variations. Also, tests were performed with both a slow and a fast BP based on closed bomb characterizations.

The test plan used was to expose standard M203 ignition system components, using both the slow and fast BP lots, to the following sequence (fig. 3):

1. Exposure for 24 hours at room temperature to either very dry air near 0% relative humidity (RH) or to wet air (using a desiccator with a saturated solution of zinc sulfate) near 90% RH.

2. Conditioning for at least 24 hours at -55°C (67°F).

3. Exposure for 5 minutes to the same dry or wet air conditions as above.

4. Assembly into the simulator and firing as soon as possible.

The entire sequence is believed to reasonably represent what could take place at a proving ground. By using only the ignition components of the charge and by performing the experiment in a laboratory environment where it is possible to maintain some control over the conditions of exposure, the results of firing in the simulator should provide at least a general quantification.

The data obtained show that exposure to high humidity, both before and after cold conditioning, will give longer ignition delay than for exposure to dry air. This conclusion is graphically represented by figure 4 and table 13, which give the range of values obtained. Appendix G shows a complete pressure versus time (P-T) trace of a typical shot. The exposure before cold conditioning with slow black powder resulted in a significant increase in ignition delay time. However, with the fast black powder, only the combined treatment of high humidity exposure both before and after cold conditioning gave a significant increase in ignition delay time. For both black powders, exposure to dry air (0% RH) before and after the cold soak gave the shortest ignition delay time. For both black powders the effect of frosting (post-exposure) had only a small effect when pre-exposure was to dry air (0% RH), but frosting did seem significant when pre-exposure was to wet air (90% RH).

Another way to represent the data is in terms of the time to reach specific events or conditions in the burning process. Table 14 shows time in milliseconds to ignition of base pad, maximum rate of pressure rise due to core burning, and initiation of the propellant. In this set of data the same conclusions are reached: the pre-exposure to wet air is more significant, the frosting has only a small effect, and the most significant influence on ignition delay is the variation, batch to batch, of black powder.

The data indicate that all postulations as initially considered have validity. Some increase in ignition delay and, therefore, in hangfire potential was seen wherever expected. Combination of effects give a more than additive result on increase in delay time. Thus, the data are seen as a confirmation of the initial speculation that the original hangfire problem was at least partially caused by the artificial nature of the circumstances; i.e., a test at −51°C (−60°F) for which preparation of charges and firing was done under conditions of high relative humidity and warm ambient temperatures (August).

The technical requirements for the M203 propelling charge have been modified to limit production loading of black powder to lots having high RQ values, and from a source which has consistently produced high RQ values.

CONCLUSIONS

1. The M82 primers were not responsible for hangfires and long ignition delays.

2. Lighter fabric on the inside of the base igniter pad expedites the attainment of the designated pressures with slow black powder.

3. The Dupont Gearhart-Owen black powder has, in general, a higher RQ than the CIL black powder and, hence, is more desirable for use in the M203 propelling charge to minimize long ignition delays and hangfires.

4. The combined effects of high humidity and cold temperature has less of an effect on high RQ black powder than low RQ black powder.

5. Aging of black powder at slightly elevated temperatures [37.8°C (100°F)] for 1 year has very little effect on the ignition delay of the M203 propelling charge.

6. There is no positive method to alter the inherent circumstances at proving grounds, although some better control might be achieved by limiting the duration and extremes of exposure seen by a propelling charge.

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2. JPG test report 78-440, May 1978.

3. L. Shulman, "A Laboratory Simulator for the Study of the Effectiveness of Ignition Systems in the 155 mm Howitzer," JANNAF Propulsion Meeting, 6 November 1973.

4. E. L. Grant, Statistical Quality Control, 3rd Ed, McGraw Hill Book Company.

Table 1. Black powder screening

Lot No.	RQ%	RF%	RQ based on GOE 75-24 = 100%
CIL 7-3	100.0	100.0	85.5
CIL 7-11	88.3	99.5	75.5
CIL 7-6	95.2	100.0	81.4
CIL 7-10	99.1	99.1	84.7
GOE 75-2	107.7	100.9	92.1
GOE 75-24	117.0	100.0	100.0
GOE 75-14	121.9	100.4	104.2
GOE 75-32	129.8	100.0	110.9
GOE 75-7	131.1	102.2	112.1
GOE 75-40	148.3	101.3	126.6
GOE 75-44	149.3	102.2	127.6
GOE 75-53	149.5	103.1	127.8
GOE 75-61	162.6	103.4	139.0

Table 2. Comparison of CIL and GOE black powder

	Lot No.			
	CIL 7-6	CIL 7-11	GOE 75-2	GOE 75-61
Moisture (%)	0.69	0.18	0.22	0.21
Specific gravity	1.79	2.77	1.77	1.72
Sieve analyses - % retained on				
US sieve No. 4	3.8	4.2	3.2	0.8
US sieve No. 5	29.8	26.9	20.6	13.9
US sieve No. 6	33.8	32.5	34.5	40.6
US sieve No. 7	16.1	17.8	20.0	23.4
US sieve No. 8	14.7	16.6	19.1	18.9
Pan	1.8	2.0	2.6	2.4

Table 3. Ballistic test comparison of ignitiion delay of M203 propelling charges assembled w/CIL or GOE black powder*

Rds	Standoff mm	Standoff (in.)	Temp °C	Temp (°F)	BP	Ignition delay Average (ms)	Ignition delay Std dev (ms)	-Δ Press kPa	-Δ Press (psi)
First occasion									
10	25.4	(1)	-53.9	(-65)	GOE	80	14	413.8	(60)
5	25.4	(1)	-53.9	(-65)	CIL	161	66	689.7	(100)
10	63.5 to 82.55	(2 1/2 to 3 1/4)	-53.9	(-65)	GOE	92	8	3,241.0	(470)
5	63.5 to 82.55	(2 1/2 to 3 1/4)	-53.9	(-65)	CIL	172	9	4,690.0	(680)
10	25.4	(1)	62.8	(145)	GOE	43	7	5,310.0	(770)
10	63.5 to 82.55	(2 1/2 to 3 1/4)	62.8	(145)	GOE	42	4	14,413.8	(2090)
Second occasion									
5	25.4	(1)	-53.9	(-65)	GOE	65	-	-	
5	25.4	(1)	-53.9	(-65)	CIL	122	-	-	
5	max		-53.9	(-65)	GOE	75	-	-	
5	max		-53.9	(-65)	CIL	133	-	-	
5	25.4	(1)	62.8	(145)	GOE	32	-	-	
5	25.4	(1)	62.8	(145)	CIL	62	-	-	
5	25.4	(1)	62.8	(145)	GOE	41	-	-	
5	25.4	(1)	62.8	(145)	CIL	68	-	-	

*From JPG test report 78-440

Table 4. Comparison of fast and slow black powder tested in ARRADCOM simulator*

No. of rds	Lot No.	Ignition delay msec	Standoff mm (in.)	Differential pressure kPa (psi)
5	W1 (slow)	X = 102	25.4 (1)	X = 69.0 (10)
	GOE-75-2	σ = 11.3		σ = 137.9 (20)
5	W1 (slow)	X = 110	54 (2 1/8)	X = 0
	GOE-75-2	σ = 4.5		σ = 0
5	W2 (fast)	X = 71	25.4 (1)	X = 793.0 (115)
	GOE-75-61	σ = 7.6		σ = 1,586.0 (230)
5	W2 (fast)	X = 79	54 (2 1/8)	X = 1,413.8 (205)
	GOE-75-61	σ = 4.0		σ = 2,206.9 (320)

*Conditiioning was at -53.9°C (-65°F).

Table 5. Effect of cloth on pressure in ARRADCOM simulator[a]

Base Igniter			Time to reach specified pressures (msec)[b]					
Group	Cloth Type	Black powder lot	689.7 kPa (100 psi)	1,379.3 kPa (200 psi)	2,069 kPa (300 psi)	2,758.6 kPa (400 psi)	3,448.3 kPa (500 psi)	4,137.9 kPa (600 psi)
P1	thin	GOE-75-61 (fast)	28-37	37-46	41-52	45-55	49-59	56-64
P2	thin	GOE-75-2 (slow)	39-46	48-55	52-63	56-68	61-68	70-85
M1	std	GOE-75-61 (fast)	28-45	35-52	39-57	42-60	47-65	58-71
M2	std	GOE-75-2 (slow)	44-60	55-70	60-74	66-80	74-86	87-100

a All samples were conditioned at -55°C and fired at -52°C

b Times shown are the minimum and maximum recorded during three or four firings per condition.

Table 6. Time required to initiate black powder fabric test

Event	Fabric wt		Time (ms)			
			Slow BP GOE-75-2		Fast BP GOE-75-61	
	(kg/m^2)	(oz/yd^2)	avg	spread	avg	spread
Initiation of base pad	0.237	7	9	4-19	4	2-7
	0.1017	3	5	-	4	3-4
Initiation of igniter charge	0.237	7	62	48-74	45	32-51
	0.1017	3	55	-	36	34-38
Initiation of propellant	0.237	7	104	95-112	92	74-123
	0.1017	3	107	-	89	86-93

Table 7. Effect of aging on ignition delay*

Storage period (month)	Ignition delay Avg (msec)	Ignition delay Std dev (msec)
0	79	11
1/4	85	13
1/2	100	9
1	87	16
3	85	10
6	101	13
9	91	10
12	92	8

* Twenty-five samples were fired for each storage period.

Table 8. Effect of moisture content on RQ of igniter components

	Storage period (month)							
	0	1/4	1/2	1	3	6	9	12
Average moisture content (%)	0.51	0.79	0.79	0.75	0.43	lost	0.75	0.78
Average RQ (%)								
Base pad[a]	117	110	104	108	116	109	105	106
Snake[b]	117	117	109	113	113	116	100	101

[a] 28.3 g (1 oz) black powder

[b] 113.2 g (4 oz) black powder

Table 9. Effect of aging on total moisture content and total volatile content of propellant

	Storage period (months)							
	0	1/4	1/2	1	3	6	9	12
Total volatiles (%)	0.23	0.33	0.23	0.24	0.27	0.29	0.48	0.45
Total moisture (%)	0.10	0.21	0.10	0.20	0.15	0.20	0.05	0.04

Table 10. Moisture content in components of M203E1 propelling charge (moisture data)

Item	Storage period (month)							
	0	1/4	1/2	1	3	6	9	12
Moisture content of components (%)								
Fiber ring	5.74	5.72	5.1	5.45	5.8	4.9	6.09	6.52
Corrugated cardboard	6.85	6.37	6.37	5.1	6.79	5.3	7.24	7.24
Cardboard spacers	5.47	5.5	5.35	3.5	6.4	4.13	7.52	7.52
Igniter tube	1.54	1.93	1.2	1.36	1.2	1.27	missing	2.07
Cloth (bag)	7.57	8.38	4.44	5.48	5.66	5.76	9.25	10.08
Cloth (sleeve)	4.9	4.7	4.50	4.05	5.18	4.18	5.86	6.00
Lead and wax liner	0.096	0.108	0.07	0.114	0.088	0.11	0.09	0.139
Flash reducer	0.003	0	0.004	0.003	0.0006	0.034	0.00126	0.0062
Total volatile content of M30A1 propellant (%)	0.23	0.33	0.23	0.24	0.27	0.29	0.48	0.45
Total moisture content of M30A1 propellant (%)	0.10	0.21	0.10	0.20	0.15	0.20	0.05	0.04

Table 11. Weight and moisture transfer of components in M203E1 propelling charge

Item	Avg item weight (g)	Moisture gain or loss Percent (%)	Weight (g)
Cardboard spacer	25	+2.05	+ 0.51
Cloth bag	851	+2.0	+17
Cloth (sleeve)	146	+1.1	+ 1.61
Corrugated cardboard	300	+0.87	+ 2.61
Flash reducer	454	+0.006	+ 0.03
Fiber ring	124	+0.8	+ 0.99
Igniter tube	147	+0.14	+ 0.21
Lead and wax liner	652	+0.043	+ 0.28
Black powder	142	+0.27	+ 0.38
		Total	+23.6
Propellant (26.2 lb)	11,895	-0.17	-20.2

Table 12. Ballistic data for the aged M203E1 propelling charge*

Storage period (mo)	Ignition delay (msec)	Velocity		Avg chamber pressure		Differential pressure		Tube pressure		Spindle pressure	
		(mps)	(fps)	(kPa)	(psi)	(kPa)	(psi)	(kPa)	(psi)	(kPa)	(psi)
0	79	814	2,670	297,241	43,100	0	0	275,172	39,900	303,448	44,000
	11	2.74	9	1,241	180	0	0	1,793	260	1,517	220
1/4	85	798	2,617	295,862	42,900	517	75	278,621	40,400	302,759	43,900
	12.8	3.8	12.6	3,862	560	1,724	250	2,206.9	320	8,965.6	1,300
1/2	100	792	2,600	297,931	43,200	1,379	200	273,793	39,700	300,000	43,500
	9.2	1.64	5.4	3,862	560	2,069	300	8,758.6	1,270	4,827.6	700
1	87	795	2,609	295,172	42,800	483	70	269,655	39,100	299,310	43,400
	16	2.35	7.7	2,621	380	1,379	200	2,275.9	330	2,551.7	370
3	85	789	2,590	288,276	41,800	1,103	160	264,138	38,300	294,482.8	42,700
	10	1.95	6.4	4,759	690	2,207	320	12,620.7	1,830	4,413.8	640
6	101	787	2,583	293,103	42,500	3,655	530	273,793	39,700	293,103	42,500
	13.4	1.77	5.8	3,586	520	3,103	450	3,241	470	2,896.6	420
9	91	794	2,605	301,379	43,700	1,931	280	274,482.8	39,800	294,482.7	42,700
	10.2	1.8	5.9	4,276	620	3,793	550	2,965.5	430	3,203	450
12	92	786.7	2,581	295,862	42,900	2,414	350	275,172	39,900	288,966	41,900
	8.2	1.62	5.3	3,586	520	2,621	380	3,103	450	3,379	490

* The first value for each of the storage periods is the average and the second is the standard deviation.

Table 13. Effect of humidity on ignitiion in ARRADCOM simulator[a]

GOE black powder lot	Time to reach specified pressures (msec)[b]						RH%
	689.7 kPa (100 psi)	1,379.3 kPa (200 psi)	2,069 kPa (300 psi)	2,758.6 kPa (400 psi)	3,448.3 kPa (500 psi)	4,137.9 kPa (600 psi)	24 hr/5 min
75-2	31-40	38-46	43-51	48-56	52-61	60-72	0/0
75-2	40-45	52-58	59-65	65-70	69-80	85-190	90/90
75-61	23-27	29-35	32-39	36-41	39-46	45-54	0/0
75-61	30-40	40-50	45-56	51-62	58-68	69-86	90/90
75-2	33-58	43-69	49-74	54-78	60-85	70-94	90/0
75-2	33-40	40-48	44-54	47-58	52-63	59-69	0/90
75-61	20-30	28-35	33-39	37-42	42-46	48-51	90/0
75-61	25-32	29-39	34-43	37-45	41-49	45-53	0/90

[a] Conditions: 1 day at 0% or 90%; 1 day or longer at -55°C; 5 minutes at 0% or 90%; firings of igniter charge at ambient temperature (-52°C).

[b] Times shown are the minimum and maximum recorded during three or four firings per condition (std cloth).

Table 14. Time required to initiate black powder (environment test)[a]

	Time (msecs) to					
	Initiate pad		Obtain max rate in core		Initiate propellant	
	BP type		BP type		BP type	
Test condition[b]	Slow	Fast	Slow	Fast	Slow	Fast
0/0	7	3	42	26	95	68
	4-11	2-4	38-44	22-29	77-109	62-72
0/90	5	3	45	35	98	74
	4-5	3-4	37-52	32-38	76-111	72-78
90/0	7	3	54	33	121	85
	4-12	-	44-69	31-35	88-148	80-88
90/90	5	3	55	46	121	85
	4-5	2-4	53-55	41-51	107-135	82-88

[a] The first entry is the average and the second entry is the spread for each of the test conditions.

[b] See figure 3 for definition of test conditions.

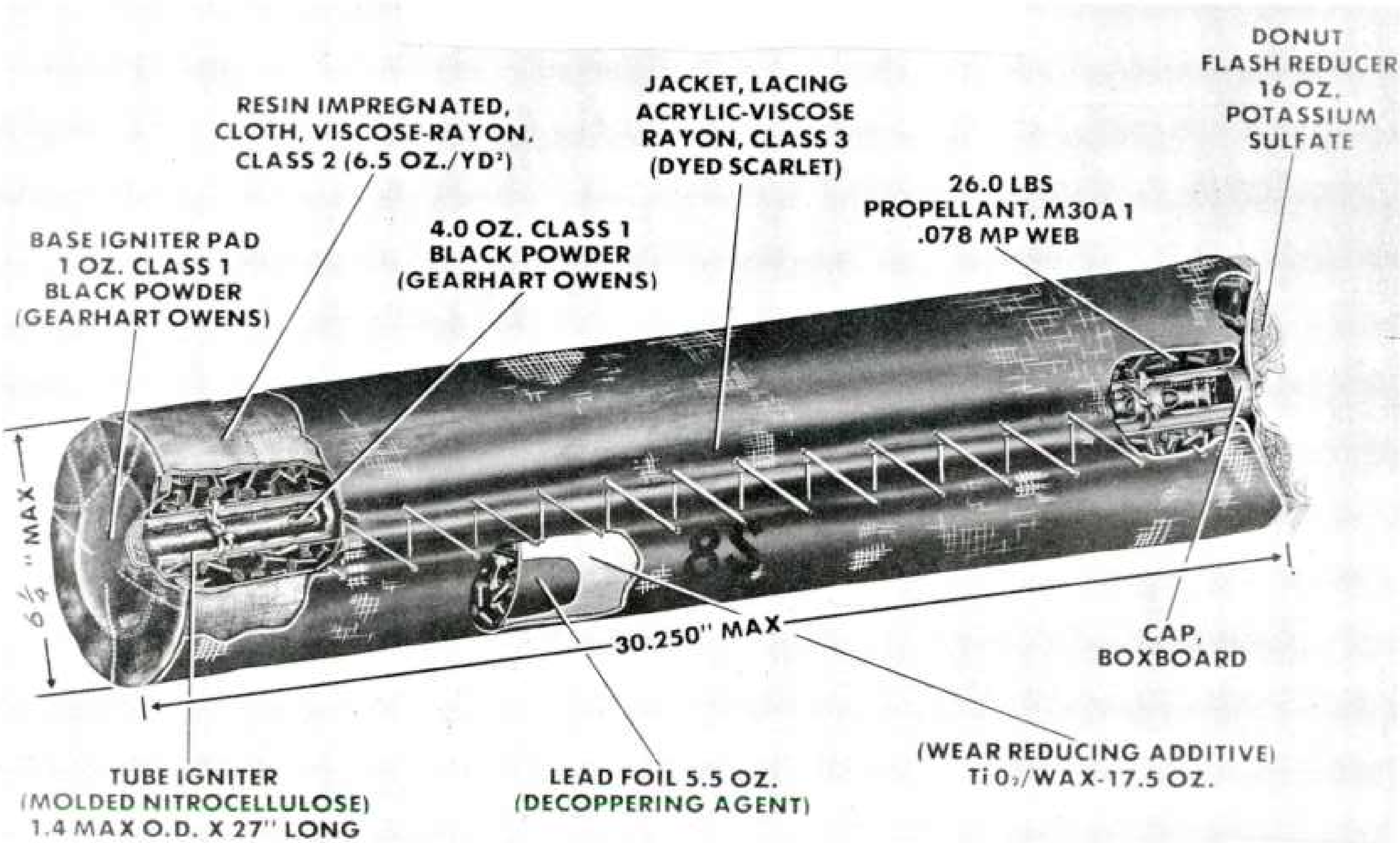


Figure 1. 155 mm propelling charge M203.

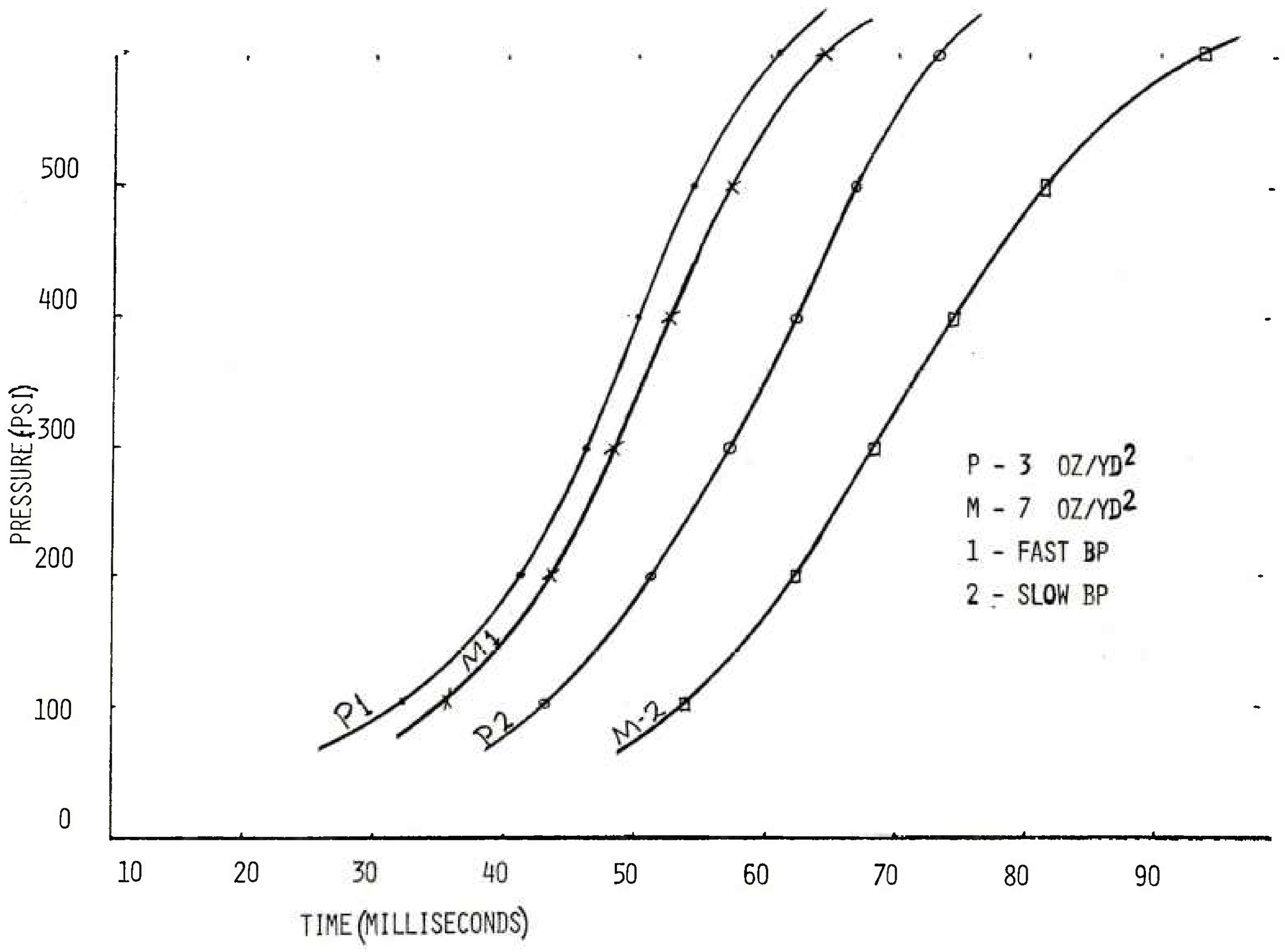
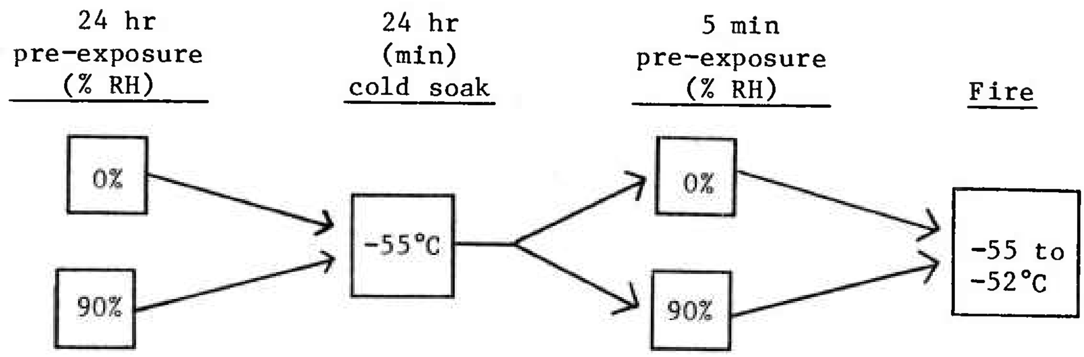


Figure 2. Pressure vs time curves for varying cloth weight and black powder.



TREATMENT*

Black powder	Pre-exposure (% RH)	Post-exposure (% RH)
Fast	0	0
Slow	0	0
Fast	90	0
Slow	90	0
Fast	0	90
Slow	0	90
Fast	90	90
Slow	90	90

* All charges conditioned at -55°C for at least 24 hours after pre-exposure.

Figure 3. Environment test matrix.

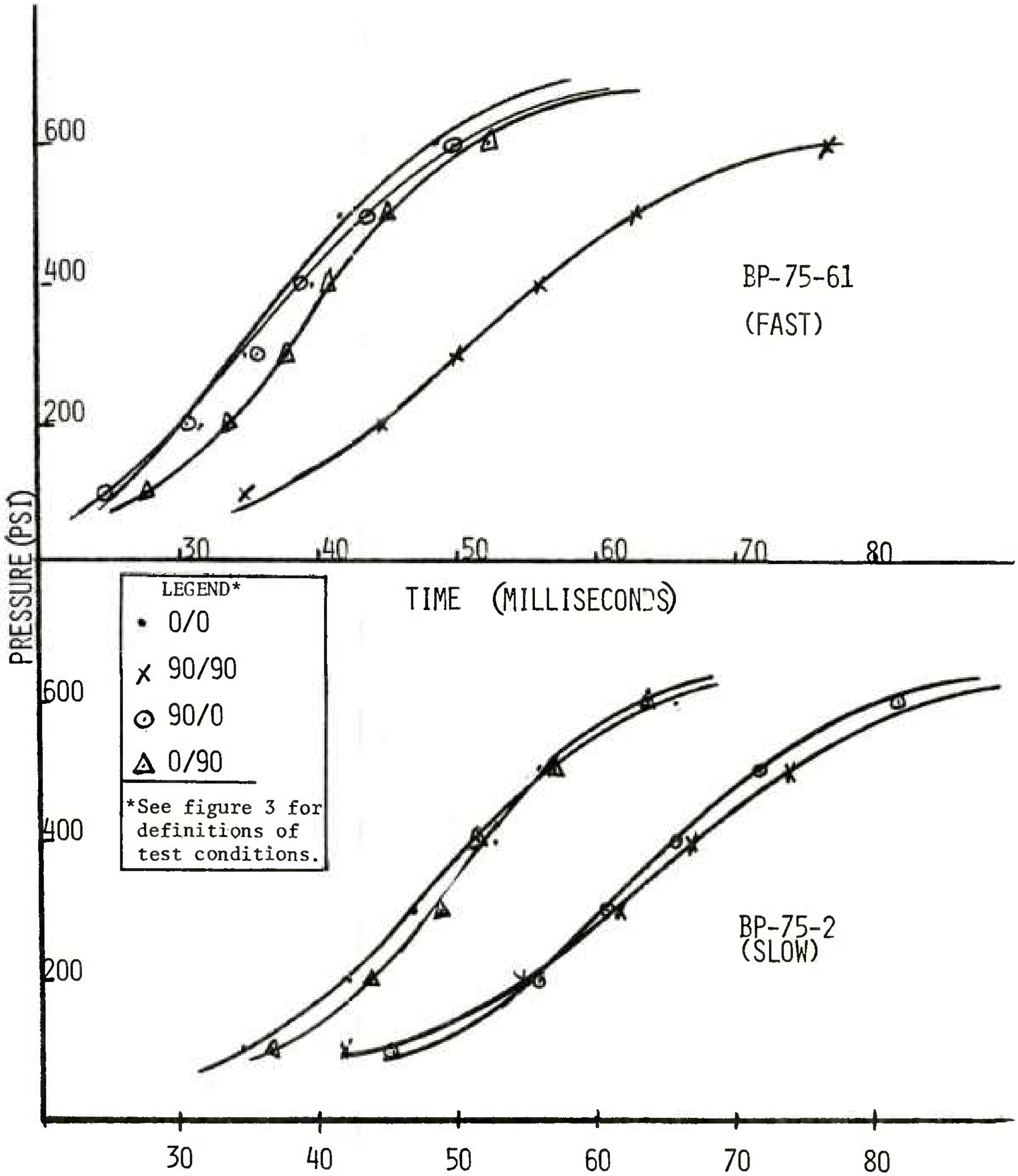


Figure 4. Pressure vs time curves for varying atmospheric conditions on black powder.

APPENDIX A. SHOP RECORD - DIAMETER AND LENGTHS OF TUBE BORE

MODEL: 155mm - M199

Tube/Ser No #73

1 Inches from Br of Tube	2 6.100 Lands (in.)	3 Diameter (lands) (in.)	4 Inches from Br of Tube	5 6.200 grooves (in.)	6 Diameter (grooves) (in.)	7 Dates
41	.022	6.122		.010	6.210	6/21/78
51	.009	6.109		.005	6.205	6/21/78
41	.022	6.122		.006	6.206	10/19/78
42	.007	6.107		.007	6.207	10/19/78
42	.026	6.126		.008	6.208	3/20/79
43	.023	6.123		.011	6.211	3/20/79
44	.022	6.122		.011	6.211	3/20/79
46	.021	6.121		.010	6.210	3/20/79
42	.035	6.135		.015	6.215	9/29/79
43	.028	6.128		.014	6.214	9/29/79
44	.028	6.128		.014	6.214	9/29/79
46	.027	6.127		.012	6.212	9/29/79
51	.020	6.120		.010	6.210	9/29/79

APPENDIX B. BALLISTIC DATA SHEET (AGING)

Date	Test round #	Rounds Fired	Month	Gun or How	Tube or Liner
10/4/78	1-25	539-567	¼	155MM XM198	155MM - #73 XM199E9
10/13/78	26-50	568-592	½	155MM XM198	155MM - #73 XM199E9
10/26/78	51-75	595-625	1	155MM XM198	155MM - #73 XM199E9
1/10/79	76-100	667-695	3	155MM XM198	155MM - #73 XM199E9
3/26/79	101-125	843-868	6	155MM XM198	155MM - #73 XM199E9
6/23/79	126-150	27-52	9	155MM XM198	155MM #27480 ** XM199E9
9/28/79	151-175	960-986	12	155MM XM198	155MM #73 XM199E9

** New Tube used.

M11 Powder Pressure Gauge

M82 Primer Lot LS 184-88

M549 Projectile

M203E1 Prop Charge temperature (-65°F)

APPENDIX C. AVERAGE MUZZLE VELOCITY

Month		$\bar{X}$	σ
¼	1	2617 fps	12.6 fps
½	2	2600	5.4
1	3	2609	7.7
3	4	2590	6.4
6	5	2583	5.8
9	6	2605	5.9
12	7	2581	5.3
TOTAL		18185	49.1

$\bar{\bar{X}} = \frac{18185}{7} = 2598$ fps

$\bar{\sigma} = \frac{49.1}{7} = 7$ fps

UPPER CONTROL LIMIT FOR $\bar{X}$

$\bar{X} = UCL\bar{X} = \bar{\bar{X}} + A1\bar{\sigma}$

$= 2598 + (1.28)(7)$

$= 2607$

LOWER CONTROL LIMIT FOR $\bar{X}$

$\bar{X} = LCL\bar{X} = \bar{\bar{X}} - A1\bar{\sigma}$

$= 2598 - 9$

$= 2589$

UPPER CONTROL LIMIT FOR σ

$\sigma = UCL\bar{\sigma} = B_4\ \bar{\sigma}$

$= (1.88)(7)$

$= 13$

LOWER CONTROL LIMIT FOR σ

$\bar{\sigma} = UCL\bar{\sigma} = B_3\ \bar{\sigma}$

$= (0.12)(7)$

$= 1.0$

$A1 = 1.28$

$B_4 = 1.88$

$B_3 = 0.12$

APPENDIX D. AVERAGE PRESSURE

Month		$\bar{X}$	σ
¼	1	42868 psi	551 psi
½	2	43168	558
1	3	42794	377
3	4	41804	691
6	5	42496	518
9	6	43734	623
12	7	42886	515
	TOTAL	299750	3833

$\bar{\bar{X}} = \frac{299750}{7} = 42,821$ psi

$\bar{\sigma} = \frac{3833}{7} = 548$ psi

UPPER CONTROL LIMIT FOR $\bar{X}$

$\bar{X} = \bar{\bar{X}} + A1\bar{\sigma}$

$= 42821 + (1.28)(548)$

$= 42821 + 701 = 43522$ psi

LOWER CONTROL LIMIT FOR $\bar{X}$

$\bar{X} = \bar{\bar{X}} - A1\bar{\sigma}$

$= 42821 - 701$

$= 42120$ psi

UPPER CONTROL LIMIT FOR σ

$\sigma = UCL\bar{\sigma} = B_4\ \bar{\sigma}$

$= (1.88)(548)$

$= 1030$

LOWER CONTROL LIMIT FOR σ

$\sigma = LCL\bar{\sigma} = B_3\ \bar{\sigma}$

$= (0.12)(548)$

$= 66$

$A1 = 1.28$

$B_4 = 1.88$

$B_3 = 0.12$

APPENDIX E. IGNITION DELAY

Month		$\bar{X}$	σ
¼	1	85 ms	12.8 ms
½	2	100	9.2
1	3	87	16.0
3	4	85	10.0
6	5	101	13.4
9	6	91	10.22
12	7	92	8.2
TOTAL		641	79.82

$\bar{\bar{X}} = \frac{641}{7} = 92$ ms

$\bar{\sigma} = \frac{79.82}{7} = 11.4$ ms

UPPER CONTROL LIMIT FOR $\bar{X}$

$\bar{X} = UCL\bar{X} = \bar{\bar{X}} + A_1 \bar{\sigma}$

$= 92 + (1.28)(11.4) = 107$

LOWER CONTROL LIMIT FOR $\bar{X}$

$\bar{X} = LCL\bar{X} = \bar{\bar{X}} - A_1 \bar{\sigma}$

$= 92 - 15 = 77$

UPPER CONTROL LIMIT FOR σ

$\sigma = UCL\bar{\sigma} = B_4 \bar{\sigma}$

$= (1.88)(11.4)$

$= 21$

LOWER CONTROL LIMIT FOR σ

$\sigma = LCL\bar{\sigma} = B_3 \bar{\sigma}$

$= (0.12)(11.4)$

$= 1.4$

$\bar{\sigma}$ = Average of the Ignition Delay Standard Deviations.

$A_1 = 1.28$

$B_4 = 1.88$

$B_3 = 0.12$

APPENDIX F. DIFFERENTIAL PRESSURE

Month		$\bar{X}$	σ
¼	1	76 psi	251 psi
½	2	197	304
1	3	73	204
3	4	155	316
6	5	533	446
9	6	280	547
12	7	352	379
TOTAL		1666	2447

$$\bar{\bar{X}} = \frac{1666}{7} = 238 \text{ psi}$$

$$\bar{\sigma} = \frac{2447}{7} = 350 \text{ psi}$$

UPPER CONTROL LIMIT FOR $\bar{X}$

$$\bar{X} = UCL\bar{X} = \bar{\bar{X}} + A_1\bar{\sigma}$$

$$= 238 + (1.28)(350)$$

$$= 238 + 448 = 686$$

LOWER CONTROL LIMIT FOR $\bar{X}$

$$\bar{X} = LCL\bar{X} = \bar{\bar{X}} - A_1\bar{\sigma}$$

$$= 238 - (1.28)(350)$$

$$= 0$$

UPPER CONTROL LIMIT FOR σ

$$\sigma = UCL\bar{\sigma} = B_4\ \bar{\sigma}$$

$$= (1.88)(350)$$

$$= 658$$

LOWER CONTROL LIMIT FOR σ

$$\sigma = UCL\bar{\sigma} = B_3\ \bar{\sigma}$$

$$= (0.12)(350)$$

$$= 42$$

$A_1 = 1.28$

$B_4 = 1.88$

$B_3 = 0.12$

APPENDIX G. TYPICAL P-T TRACES GENERATED IN ARRADCOM 155 MM SIMULATOR DURING ENVIRONMENTAL STUDY.

The following four figures graphically show the pressure-time (P-T) history in the simulator.

Figures G-1 and G-2 are P-T traces from a gage located at the front and rear of the chamber. The first little spike shows when the primer fired. The first steep rise in pressure represents the burning of the base pad and snake. The second rise, which is slow, shows the burning of the propellant.

Figures G-3 and G-4 are derivatives of the P-T traces. All the ignition-burning phases can be followed easier in these plots.

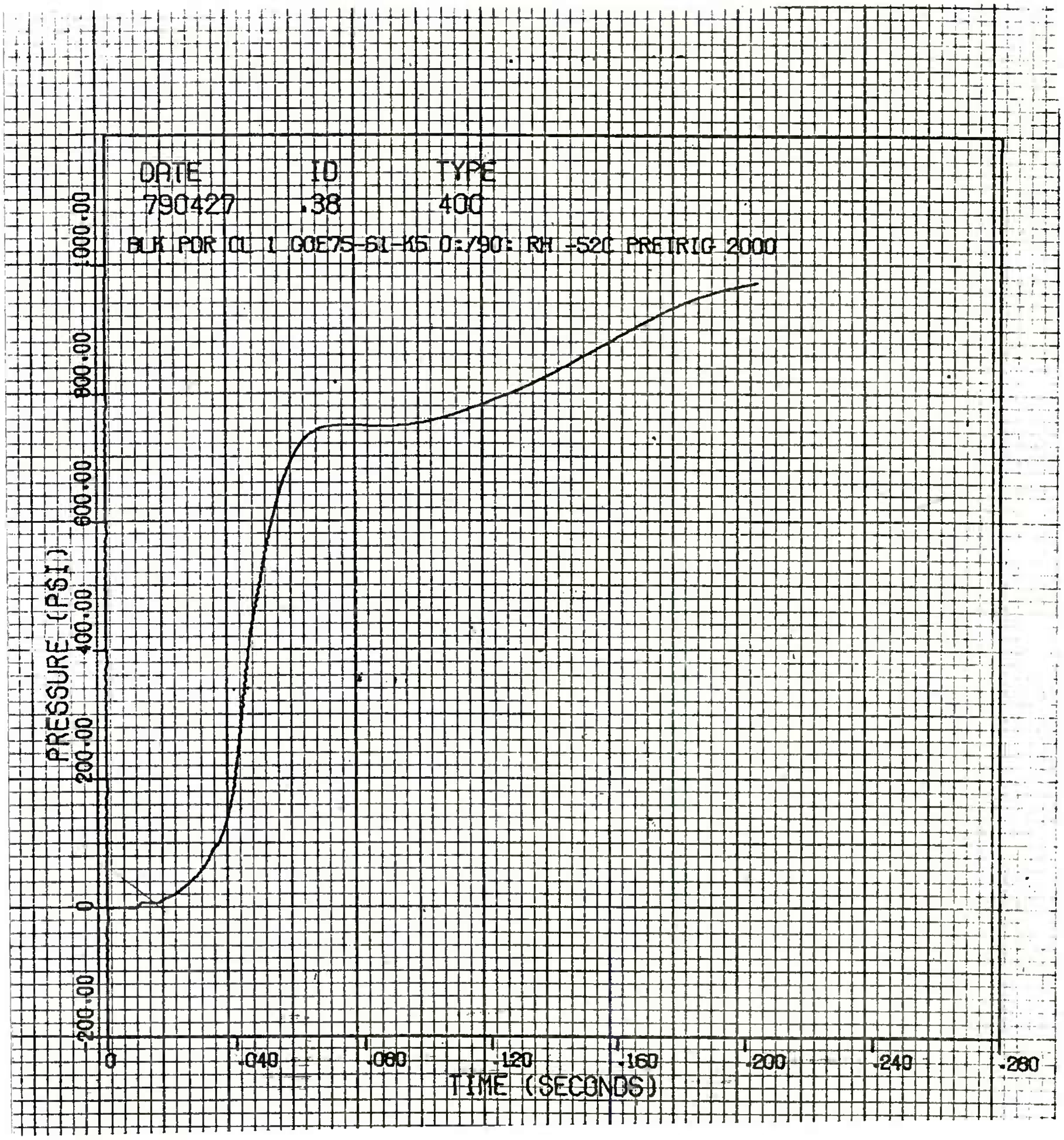


Figure G-1. P-T trace - gage at front of chamber.

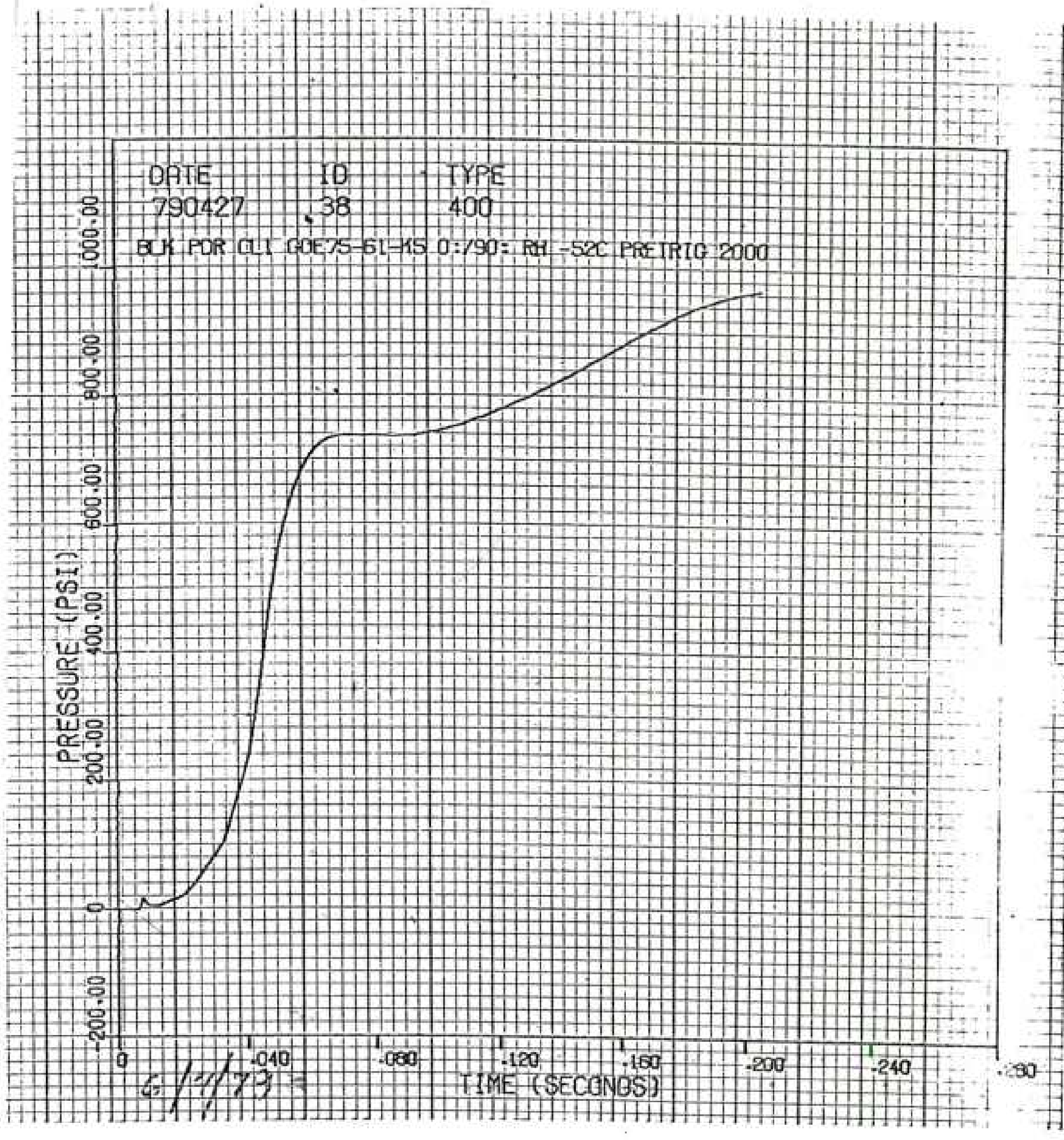


Figure G-2. P-T trace - gage at rear of chamber.

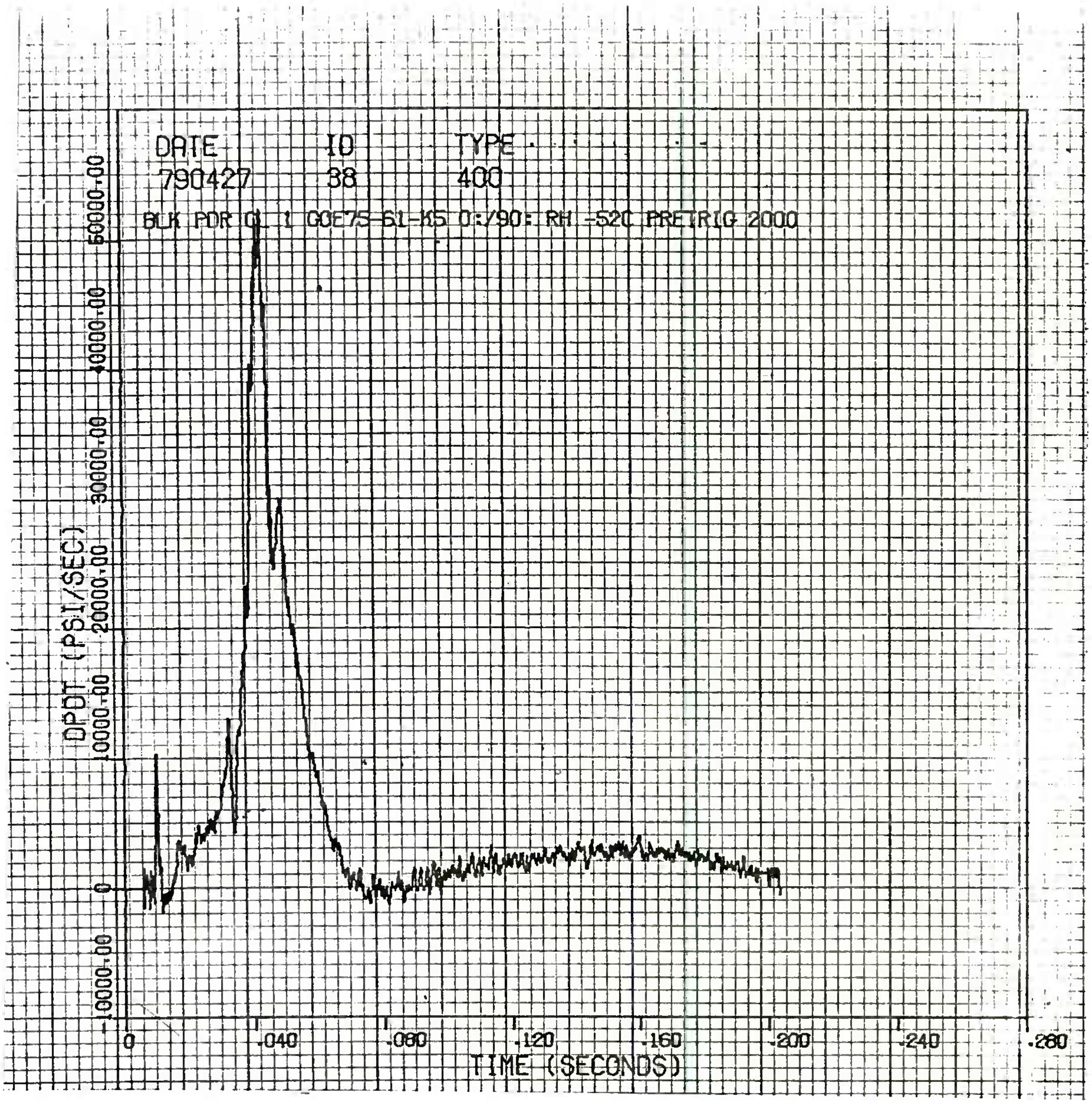


Figure G-3. Derivative of P-T trace - gage at front of chamber

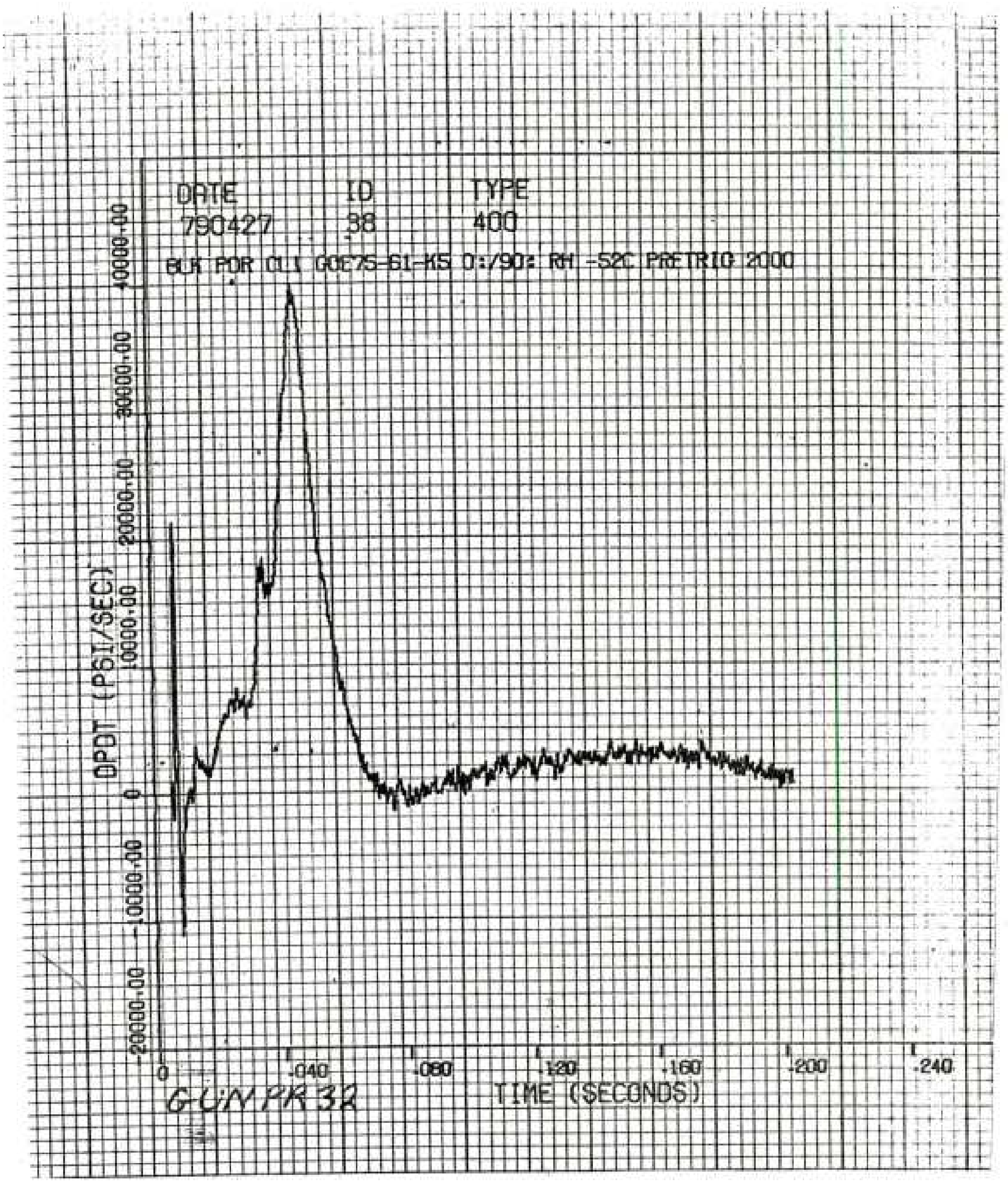


Figure G-4. Derivative of P-T trace - gage at rear of chamber

Abbreviations

CIL	Canadian Industries Limited
BRL	Ballistic Research Laboratory (Aberdeen, MD)
HOW	Howitzer
Prop	propellant
DUP-GOE	Dupont Gearhart-Owen
GOE	Gearhart-Owen
JPG	Jefferson Proving Ground
LCWSL	Large Caliber Weapon System Laboratory (Dover, NJ)
NC	nitrocellulose
Snake	Sleeve portion of the base igniter loading assembly
seven occasions	(1/4, 1/2, 1, 3, 6, 9, 12 months)
MP	multi-perforated
RQ	relative quickness
MPa	megapascal
BP	black powder
kPa	kilopascal

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