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MARYLAND

REPORT
BRL No. 339

ON THE USE OF CO_2 AS A PROPELLANT IN GUNS

ORDNANCE RESEARCH & DEVELOPMENT CENTER

PROJECT NO.________

Ballistic Research
Laboratory Report No. 339

JHF/JRL/emh
Aberdeen Proving Ground, Md.
March 12, 1943

ON THE USE OF CO_2 AS A PROPELLANT IN GUNS

Abstract

A thorough study of the possibilities of using CO_2 as a propellant in guns was made. The work was divided into two phases: (1) the use of solid CO_2 in addition to FNH powder in rifled guns. (2) The use of liquid-vapor CO_2 under pressure either alone or with a heater for unrifled guns. In the first case, the effect of the addition of solid CO_2 resulted mainly in the reduction of the muzzle velocity - even more than if an inert material had been used instead of the solid CO_2. In the second case, the heater used as propellant without CO_2 gave a smoother, more constant pressure-time curve than with the CO_2 but the pressure-time curve obtained with service propellant powder in other guns is much smoother than any obtained in these firings.

The Chief of Ordnance requested the Ballistic Research Laboratory to make a thorough study of the feasibility of using CO_2, either in the solid or liquid form, as a propellant for rifled or unrifled guns.

The first program carried out was outlined in its entirety by a representative of the Chief of Ordnance. The purpose of this firing was to substitute chunk or pulverized solid CO_2 for propellant increment charges in some zoned weapon, preferably a howitzer. Firings were started with solid CO_2 because it was the most readily available form of CO_2.

The term zoned weapon defines, in this case, a howitzer which propels the projectile at several different velocities, these velocities depending upon the particular charge or weight of powder used. The purpose of firing at lower than maximum velocities is to get high angle fire, which results in high angle bursts, and also to save the gun from excessive erosion. Thus the 105mm Howitzer has seven zones, as follows:

Zone	Charge oz.	Velocity f/s
I	10.64	650
II	12.68	710
III	15.14	780
IV	18.60	875
V	24.14	1020
VI	32.80	1235
VII	46.30	1550

The first phase of the CO_2 program consisted of substituting equal weights of solid CO_2 for removed organic propellent powder. The organic propellent powder was the service smokeless, Flashless, non-hygroscopic type of propellant.

The two howitzers chosen for the CO_2 firings were the 105mm Howitzer and the 75mm Pack Howitzer. The 105mm Howitzer is the most important weapon used by the Field Artillery in the present war. It fires a thirty-three pound projectile for a range of as much as 12,200 yards. The Pack Howitzer is probably the most mobile Field Artillery weapon and may be carried over mountains and streams on pack mules or on snow sleds.

The results obtained in these two howitzers are given in the following table:

105mm Howitzer Firings

Rd. No.	Base Charges FNH Lot 5682	Increment Charge FNH Lot 5682	CO_2 Charge oz.	Muzzle Vel. f/s	Note
1	11 oz.	9 oz.	0	955	NO CO_2
2	11 "	9 "	0	954	NO CO_2
3	11 "	5 "	4	811	Pulverized CO_2 in paper bag ahead of primer
4	11 "	5 "	4	794	Pulverized CO_2 mixed with increment powder.
5	11 "	5	0	816	NO CO_2
6	11 "	5	0	848	NO CO_2
7	11 "	2	7	683	Pulverized CO_2 mixed with increment powder
8	11 "	2	7	685	" " "
9	11 "	0	9	650	" " "
10	11 "	0	9	648	" "

75mm Pack Howitzer Firings

Rd. No.	Base Charges FNH Lot 8688	Increment FNH Lot 8688	CO_2	Muzzle Vel. f/s	Piezo-electric Press.
1	6.0 oz.	9 0 oz.	0	1248	
2	6.0 "	9.0	0	1248	31,600 lb/in²
3	6.0 "	5.0	4.0	906	13,850 "
4	6.0 "	5.0	4.0	932	16,200
5	6.0 "	2.0	7.0	758	10,750
6	6.0 "	[illegible]	7.0	724	[illegible],800
7	6.0 "	0	9.0	693	9,600
8	6.0 "	0	9.0	678	10,200
9	6.0 "	0	0	701	9,800
10	6.0 "	0	0	690	8,700

An inspection of these tables shows the effect of the replacement of propellent powder by CO_2. The first two rounds fired in the 105mm Howitzer were with a total charge of 20 ounces of the service powder; the second set of two rounds (Rds. 3-4) were also with 20 ounces of total charge, but of this total charge four ounces were pulverized CO_2 and sixteen were service powder. The velocity dropped from the 955 f/s and 954 f/s obtained on the first two rounds (Rds. 1-2) to 811 f/s and 794 f/s obtained on the second set of two rounds (Rds. 3-4). In other words, substituting 4 oz. of CO_2 for four ounces of service powder resulted in a drop in velocity of 152 f/s.

The next two rounds (Rds. 5-6) were fired with 16 ounces of service powder without any CO_2; the velocities for these two rounds were 816 and 843 f/s or an average of 832 f/s. The two rounds with 4 oz. of CO_2 and 16 oz. of service powder (Rds. 3-4) gave a velocity lower by 29 f/s than the two rounds (Rds. 5-6) without any CO_2 and with 16 oz. of service powder. Firing thirteen ounces of service powder plus seven ounces of CO_2 gave velocities of 683 f/s and 685 f/s while a charge of 11 ounces of service powder plus nine ounces of CO_2 gave velocities of 650 f/s and 648 f/s. It is apparent from these results that solid CO_2 is not a suitable substitute for service propellent powder in gun firing.

Somewhat similar results were obtained in the 75mm Pack Howitzer. Fifteen ounces of service powder gave a 14.70 lb. projectile a velocity of 1248 f/s (Rds. 1-2). Reducing the powder charge by four ounces and firing the 14.70 lb. projectile with eleven ounces of service powder plus four ounces of CO_2 reduced the velocity by 329 f/s to 906 f/s and 932 f/s (Rds. 3-4). Another reduction of three ounces in weight of service powder with the corresponding addition of three ounces of CO_2 further reduced the velocity to 758 f/s and 724 f/s (Rds.5-6). The last group of firings was made with six ounces of service powder; when nine ounces of CO_2 were added the velocities were 693 f/s and 678 f/s (Rds 7-8) while without the CO_2 the velocities were 701 f/s and [illegible] f/s (Rds. 9-10).

It is evident from these results that the solid CO_2 replacing an equivalent amount of propellent powder not only gives, in every case, a velocity lower than that obtained with the powder but even gives a velocity as low or lower than that obtained by omitting the CO_2 completely. Any inert material added (such as sawdust or cereal) would have increased the velocity over that obtained by the propellent powder alone. The solid CO_2, both because of its low temperature and high specific heat and heat of vaporization, reduces the velocity.

A program of firings with liquid CO_2 in a specially constructed gun agreed upon at a conference held at the Ballistic Research Laboratory on February 2nd is attached. As outlined in this program, a Cardox mine cartridge was used as container for the liquid-vapor CO_2.

The gun barrel was a tube 2" in inner diameter, 4" in outer diameter and 10' 8" in length.

A gun tube length of at least sixty calibers for the CO_2 Gun was specified at the conference held at the Ballistic Research Laboratory. In order to compare the length of this gun with the lengths of the two howitzers considered previously, a tabulation of lengths is given below:

Gun	Travel
CO_2 (2" Bore)	61 calibers
75mm Pack Howitzer	13 calibers
105mm Howitzer	20 calibers

It is evident that this CO_2 gun has a very much longer travel than any gun firing at about the same velocity. One of the longest service guns is the high velocity (3000 f/s) 4.7" A.A. gun; yet this gun has a travel of only 53 calibers. The importance of the long travel length lies in the added weight and added difficulty of manoeverability and of elevation.

The inside of the gun tube was reamed to a smooth finish in the shop of the Ballistic Research Laboratory under the immediate supervision of the Chief Mechanic, Mr. L. F. Bauer. A special contact called the muzzle contact for determining the time when the projectile left the muzzle was mounted on the muzzle end and the breech end was threaded for about an inch and a half for mounting the Cardox cartridge.

The Cardox Cartridge is a empty shell 46-5/8" long with an electric firing plug and special filling valve at one end and a patented gas escape plug at the other end. The gas escape plug is seated against a blow-out pressure disc. To the firing plug is attached an electric match set into a cardboard tube containing a mixture of potassium perchlorate ($KClO_4$) and Charcoal (C). The Cardox cartridge is then filled with liquid-vapor CO_2. When used for blasting coal, the heating mixture ($KClO_4$ and C) is ignited by the electric match and the pressure built up by the heated CO_2 bursts the blow-out disc and the CO_2 escapes from the vents. For the firing in the gun a special fitting was made which served to hold the blow-out disc in the cartridge, to line up the shell in the gun, and also, with a special collar which fitted over the Cardox shell, to obturate the gases at the joint between the gun tube and the Cardox shell. A small rubber ring designed on the "Bridgman unsupported-area principle" was the only washer used at this point.

Five inches from the breech face a piezo-electric pressure gage was mounted. This gage consists essentially of a stack of quartz crystals, the plane faces of which are cut perpendicularly to their electric axis. The application of pressure develops a proportional electro-static charge which, after amplification, may be recorded as the deflection of an electron beam by a photographic film moving on a revolving drum. In this way a complete pressure-time curve may be obtained.

The entire gun (barrel plus Cardox shell) was mounted on a heavy wooden slide which was free to recoil in a wooden trough for a length of about three feet. Two springs were placed at this distance to take up the remaining recoil energy.

Photographs and a sketch of the gun and the recording apparatus are attached.

The projectiles used were 57mm proof projectiles turned down to a diameter of two inches and a weight of 5 lbs. These projectiles were machined to a smooth finish and their fit in the gun was so good that when they were inserted into the gun from the muzzle end, the air between the projectile and the breech was compressed.

One round was fired using CO_2 only as propellant and a No. 8 detonating cap to blow the pressure disc in the cartridge. Both pressure and velocity were too low to be measured by the available apparatus but the latter may be estimated from the fact that the slug dropped six inches in 36 feet, which corresponds to a velocity of about 200 f/s. If CO_2 alone is used as propellant, the velocity of the projectile will depend upon the air temperature since the velocity depends upon the accelerating pressure and the accelerating pressure is the vapor pressure of CO_2. Thus this pressure when the air temperature is 88° F will be 2.5 times that when the air temperature is 20°F. This variation in pressure causes a variation in velocity which, in turn causes a variation in range. A variation in range depending upon the air temperature, is of course, not a practical condition for a military weapon. In addition, the velocity of a CO_2 gun will be exceedingly low at cold temperatures.

Another possible application of CO_2 is its use with a chemical heater. This is the principle used by the Cardox cartridge and described previously.

Several rounds were fired using this cartridge with different sizes of heaters with the following results:

Charge	Max. Pressure	Velocity (at 45')
50 grams heater +1.5 lb. CO_2	3290 lb/in²	550 f/s
110 " " +1.7 " "	9360 "	756
110 " " No. CO_2	7130 "	869
110 " " "	6520	Lost

Photostats of the pressure-time curves of these rounds are attached. It is evident from a study of these records that none of the curves has characteristics which approximates the advantageous characteristics claimed for CO_2 as propellant:

(1) A pressure-time curve having a very gradual rise which would not subject the projectile to shock,
(2) A smooth, constant pressure-time curve.

Upon the suggestion of Mr. Monner, two rounds were fired with the heater in a steel tube placed well to the front of the Cardox shell in such a position that its forward end was immediately behind the blow-out disc, and ignition was effected at the forward end. In the firing of the first round the steel tube was shot out of the gun and a small blue flash was observed at the muzzle. In the second round, the steel tube was flared so that it was held in place. The steel tube was ruptured for a length of eight inches so that it was extremely difficult to remove it from the Cardox cartridge. Both of these rounds were ignited at the muzzle end of the heater tube. Below are given the pressures and velocities obtained on these grounds.

Charge	Max. Press.	Velocity (at 45')
65 gm heater + 1.54 lb. CO_2	4380 lb/in²	646 f/s
[illegible]5 gm heater + 1.50 lb. CO_2	6460 lb/in²	486 f/s

For comparison, there is attached a pressure-time curve obtained in a 155mm Howitzer firing organic propellent powder. It is evident that this curve has a much more gradual rise than any of the curves obtained in the present series of firings.

It may also be stated that liquid-vapor CO_2 cannot be fired without a blow-out pressure disc. Such an arrangement entails a sudden blow on the base of the projectile, even when a relatively low pressure disc was used. One one occasion, the shell was disassembled without firing and it was found that the blow-out disc was bulged. For safety it would therefore be necessary to use a higher pressure blow-out disc with a resultant higher initial pressure on the base of the projectile.

The present firings were all made with the gun at an elevation of zero degrees. However, the results obtained (pressure and velocity) would be a function of the elevation of the tube, since the elevation determines the position of the liquid with respect to the heater. In these firings, moving the heater with respect to the CO_2 (Mr. Monner's suggestion) was shown to affect the velocity. This feature, too, it not a desirable one for a service weapon.

Mention should be made of the weight of the holder for the liquid CO_2. Since it is necessary to withstand a pressure up to 10,000 lb/in^2 the cartridge containing the liquid CO_2 must be fairly substantial. The empty Cardox cylinder used weighs about seventeen pounds, while the cartridge case and powder for the 75mm Pack Howitzer weigh only about three pounds.

If solid CO_2 were used, the transportation problem would be quite difficult. The solid CO_2 is not stable at atmospheric temperatures and the evaporation would be considerable in one day unless special precautions were taken to cool or insulate the container.

This report is a study of firings made with solid CO_2 and liquid CO_2. No attempt was made to use gaseous CO_2 introduced into a cartridge case under pressure. The difficulties of obturating such a system (cartridge case and projectile) are obvious. In addition, the CO_2 would be definitely inferior to other gases since it is a triatomic molecule with a molar heat greater than that of the powder gases. It follows that heat would be absorbed in heating the CO_2 and the resultant partial pressure of this heated CO_2 would be less than the reduction in pressure of the powder gases due to the heat lost. In other words, the mixture of powder gases and gaseous CO_2 would have a higher temperature for the corresponding pressure than the powder gases without the CO_2 or powder gases mixed with gases of smaller molar heat than CO_2.

CONCLUSIONS:

(1) Solid CO_2 added to propellent powder performs no useful function.

(2) Liquid-vapor CO_2 alone is not feasible in guns because the vapor pressure is a rapidly varying function of the temperature of the CO_2. This results in the velocity and the range both being rapidly varying functions of the air temperature of the day.

(3) Liquid-vapor CO_2 plus a heater, under the conditions tried out, gives a pressure-time curve considerably steeper and more undular than propellent powder.

ACKNOWLEDGMENTS

The undersigned wish to express their appreciation to Dr. du Mazuel of the Office of the Chief of Ordnance, to Mr. Monner of the Colorado Research Laboratories, and to Dr. Getz of the Cardox Mine Cartridge Corporation for their advice and cooperation in the completion of this program.

J. H. Frazer

J. H. Frazer
1st Lt., Ord. Dept.

J. R. Lane

J. R. Lane

CONFIDENTIAL

PROGRAM FOR CO_2 GUN

On February 2nd after the firing of the 75mm and 105mm Howitzers using CO_2 in addition to FNH powder as propellant, a conference was held in Colonel Simon's office to discuss the further applications of CO_2 to ordnance. Present at the conference were the following:

Office of the Chief of Ordnance:	Col. Gerhardt, Dr. DuMazuel
Ballistic Research Laboratory:	Col. Simon, Mr. Kent, Lt. Frazer, Mr. Lane
Cardox Mine Cartridge Corp.:	Dr. Getz
Consultant:	Mr. Monner

At this conference a program was drawn up and agreed upon by the conferees as the most likely to yield results upon which to judge the practicability of using CO_2 as a propellant. It was agreed by everyone that the advantage of using CO_2 lay in the possibility of obtaining a constant pressure-time curve. In order to determine whether such a curve is obtained the following program was agreed upon:

(1) If feasible, and immediately available, fire a round with CO_2 (liquid) alone bursting a blow-out disc either mechanically or by a small charge of high explosive. This disc to be placed between the CO_2 container and the gun tube.

(2) Fire a standard Cardox mine cartridge containing CO_2 (liquid) and various charges of the potassium perchlorate-charcoal heater. Again a blow-out pressure disc was to be placed between the Cardox cylinder and the gun tube. In the Cardox cartridge the heater is placed in a cardboard tube and is ignited electrically by a match in the rear (breech) end.

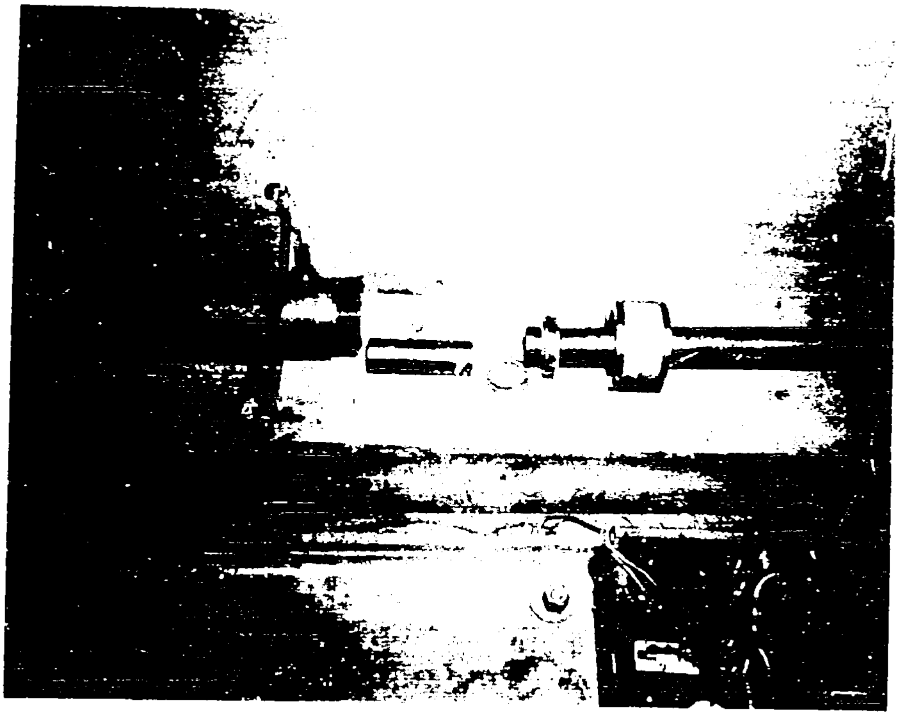
(3) Repeat firing (2) above with the modification of placing the [illegible] in a [illegible] tube and igniting the heater at the front (muzzle) end.

It was decided that a 2" I.D. tube, 60 calibers long, would be satisfactory. The projectile for this tube was to be a [illegible] lb. [illegible]. The tube was to be a smooth bore.

No further work was to be done without specific orders from the Chief of Ordnance.

J. R. Lane.

CONFIDENTIAL



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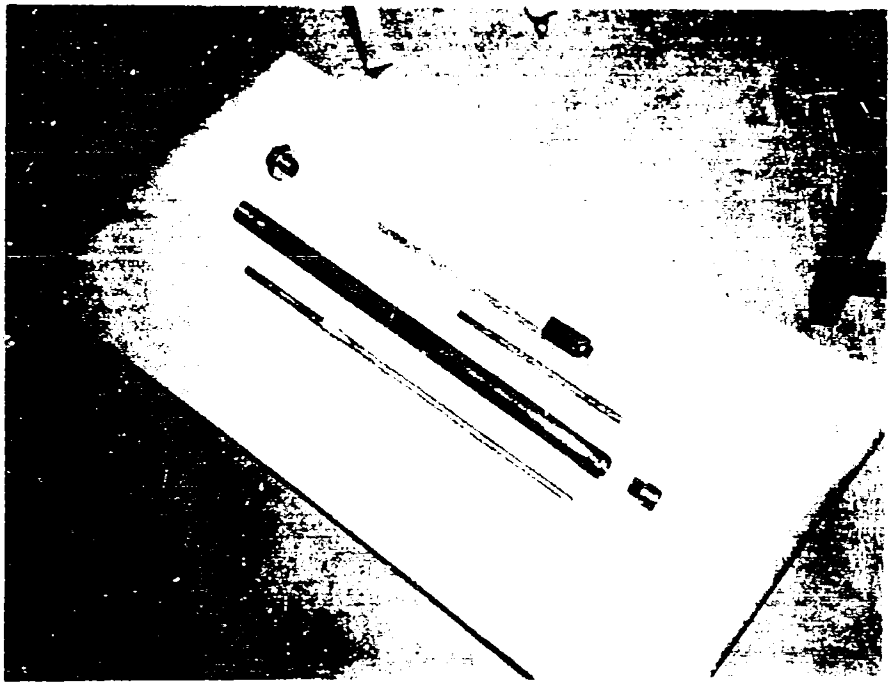

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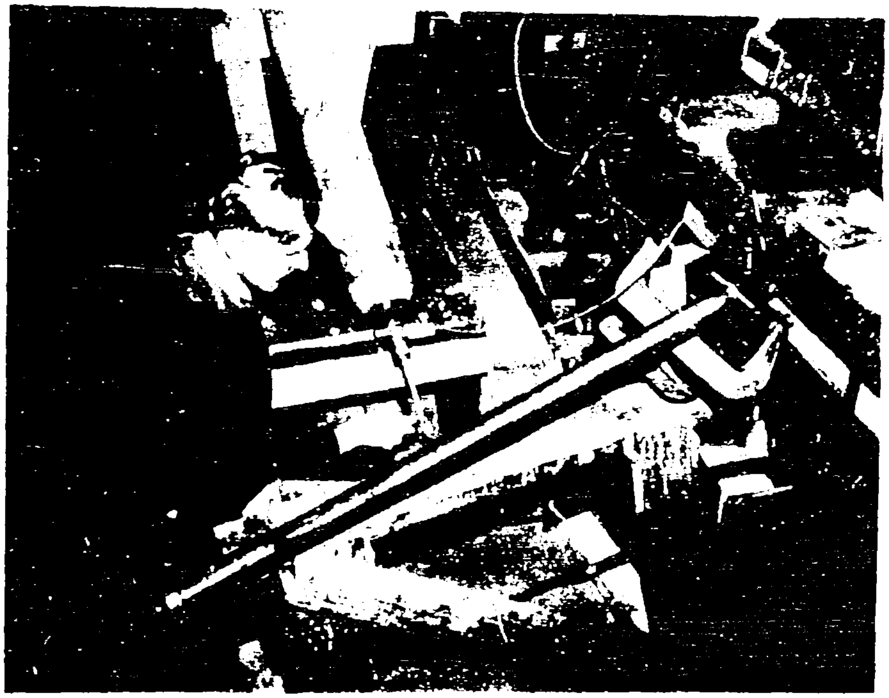

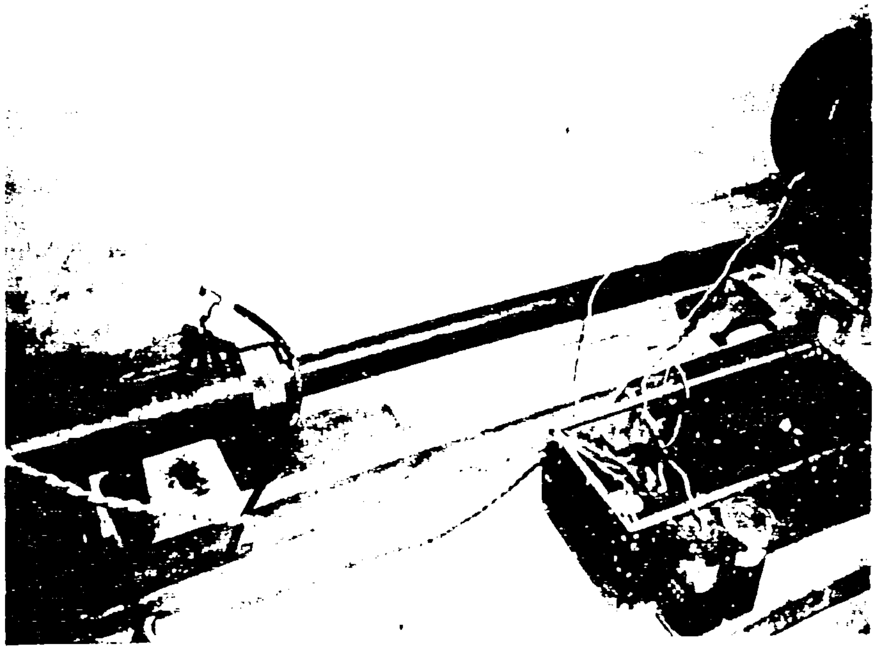

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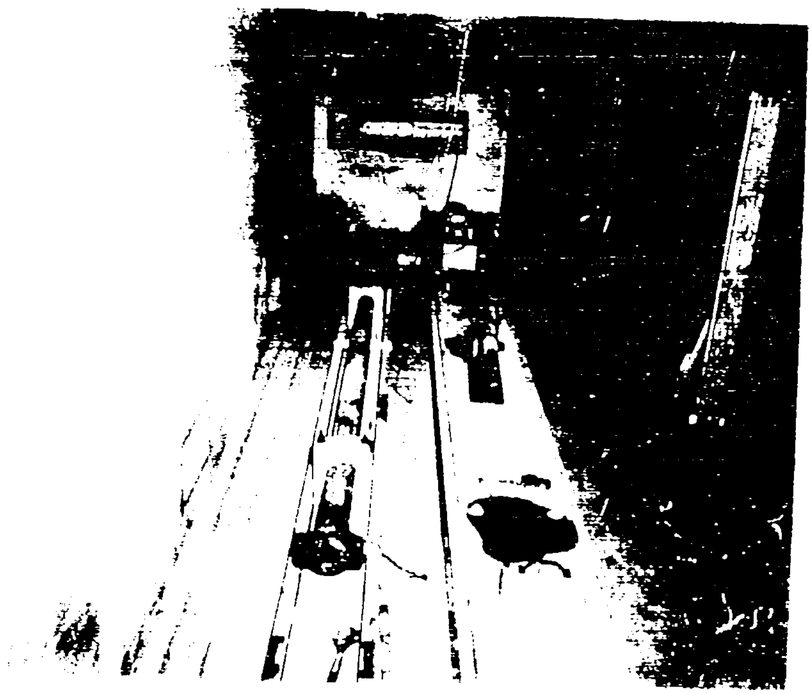

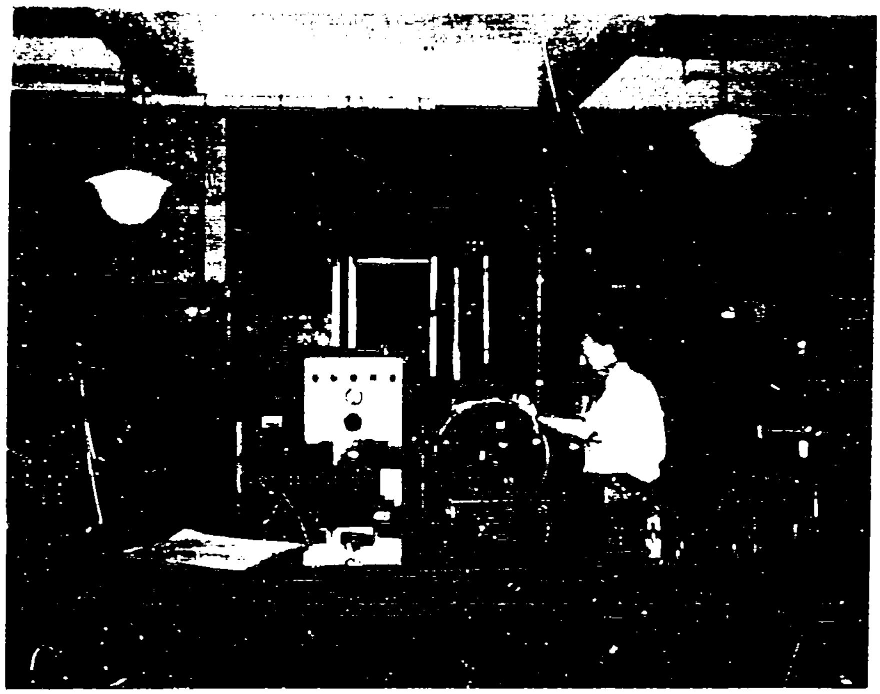

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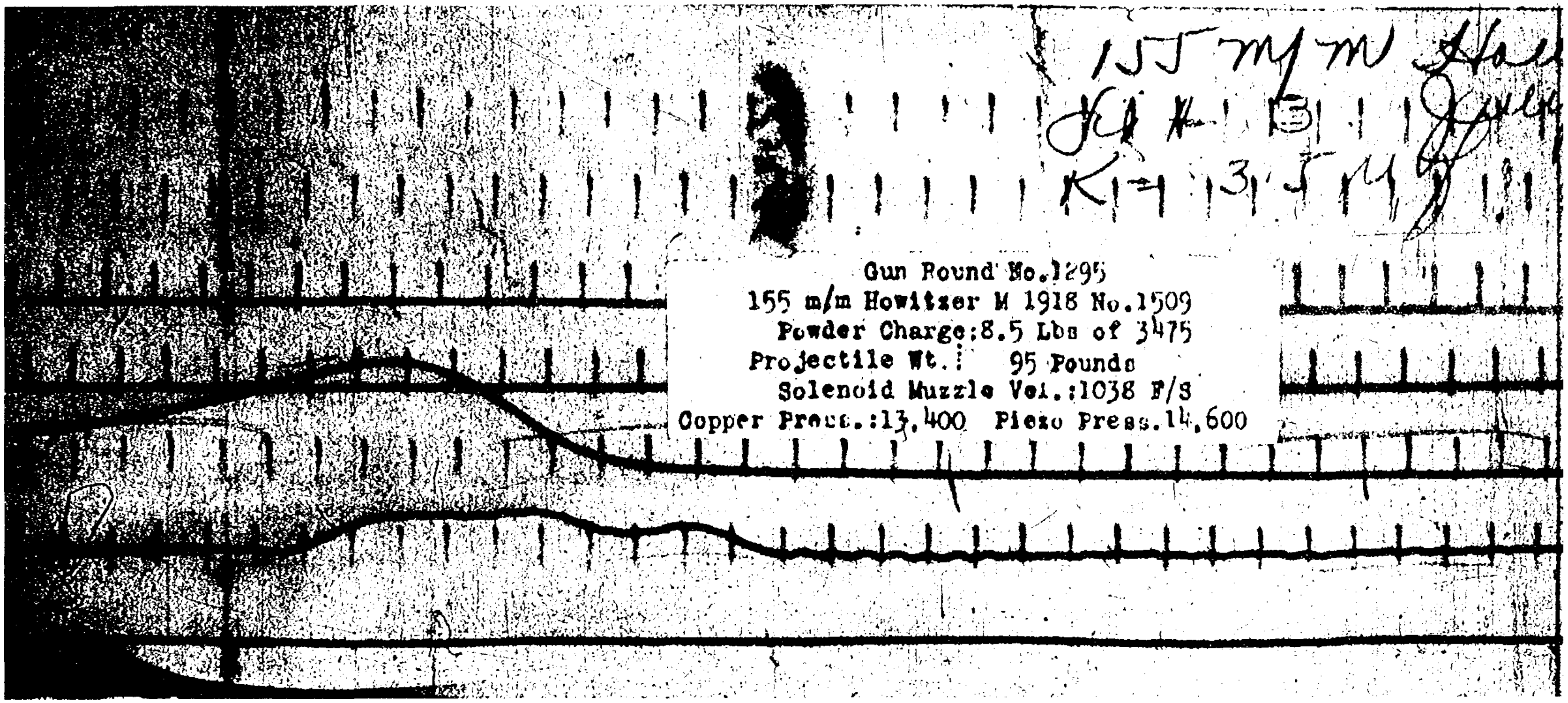
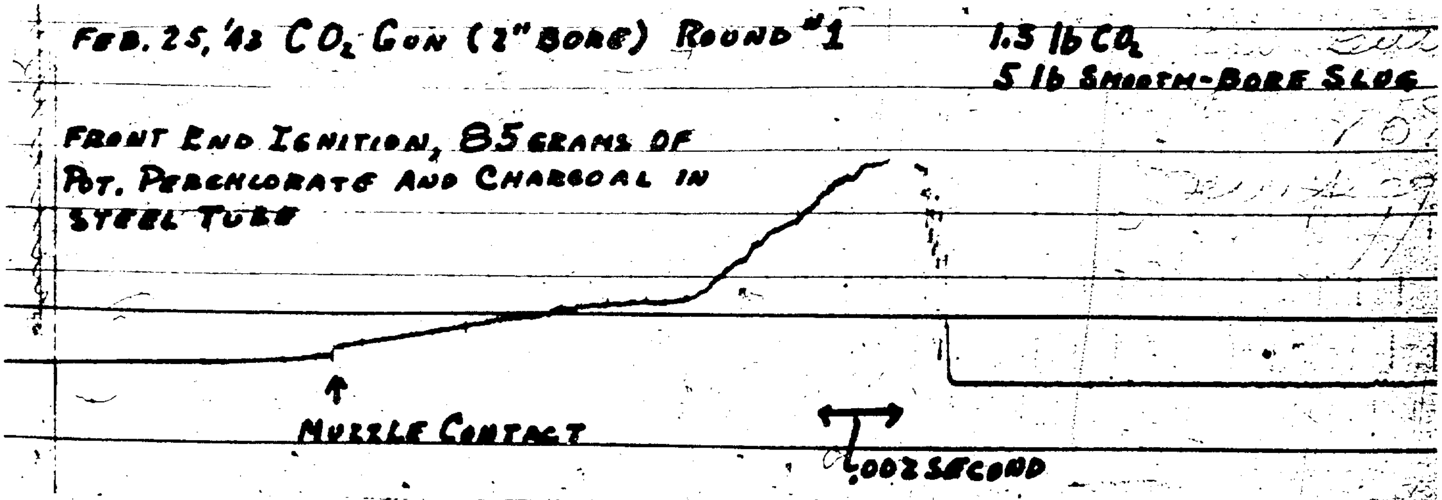
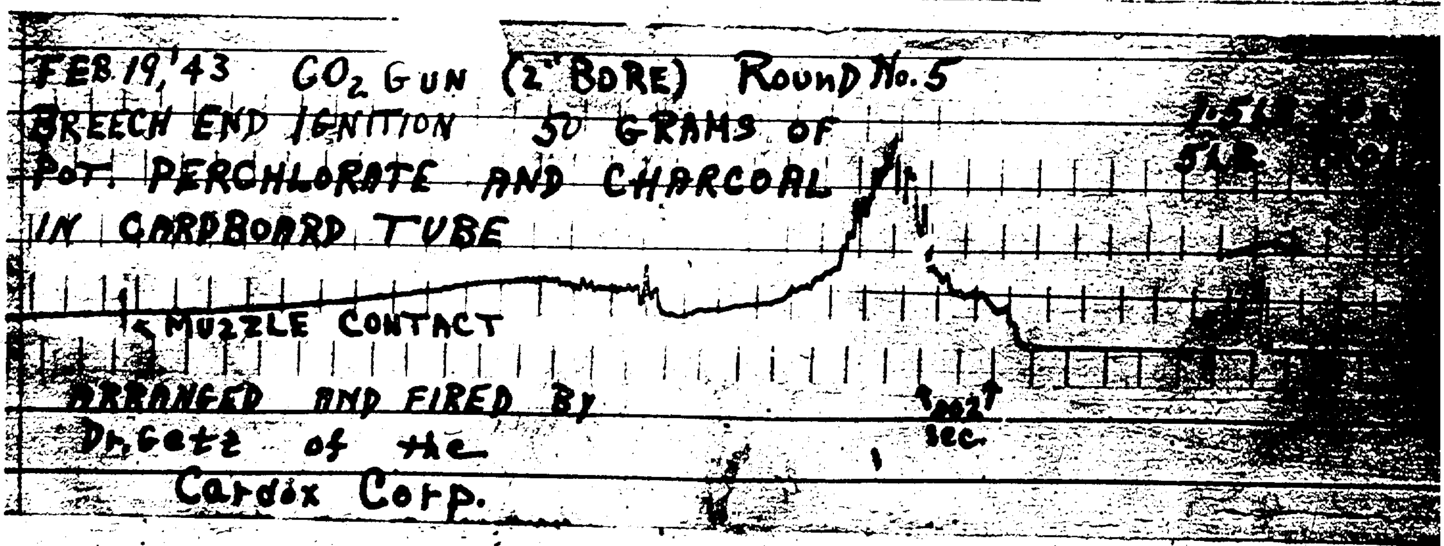
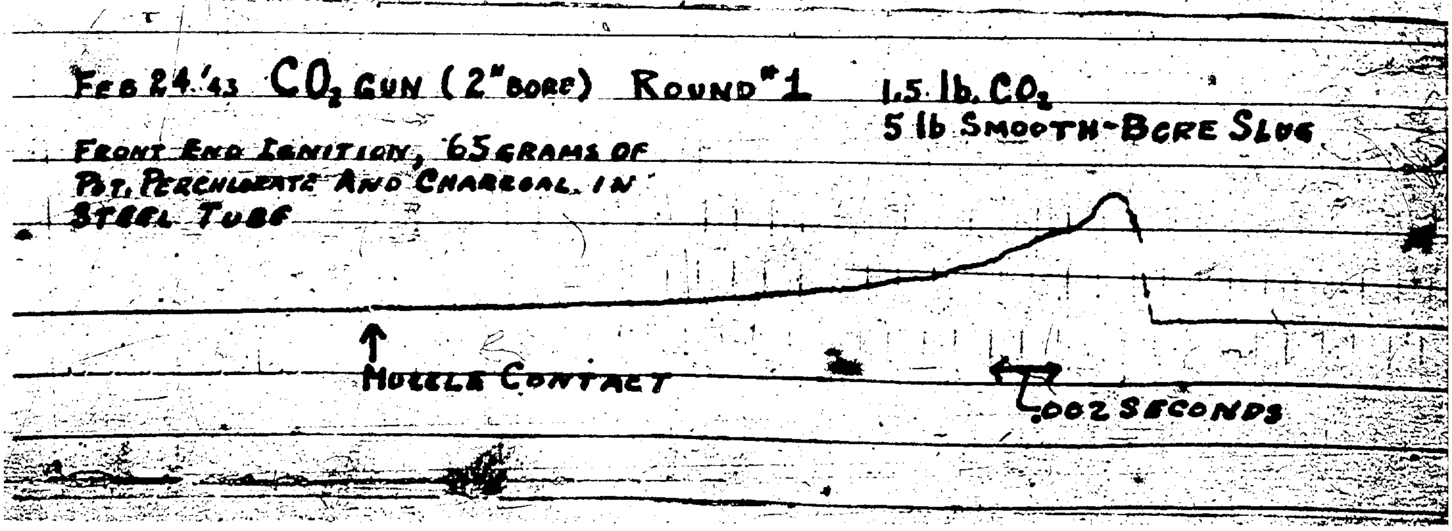
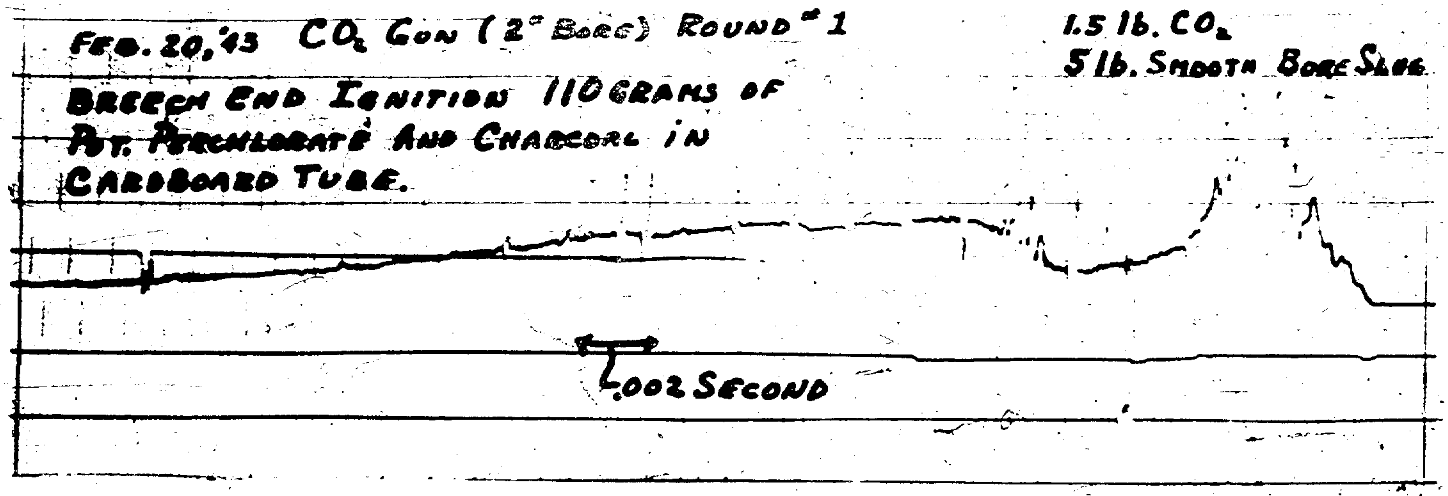
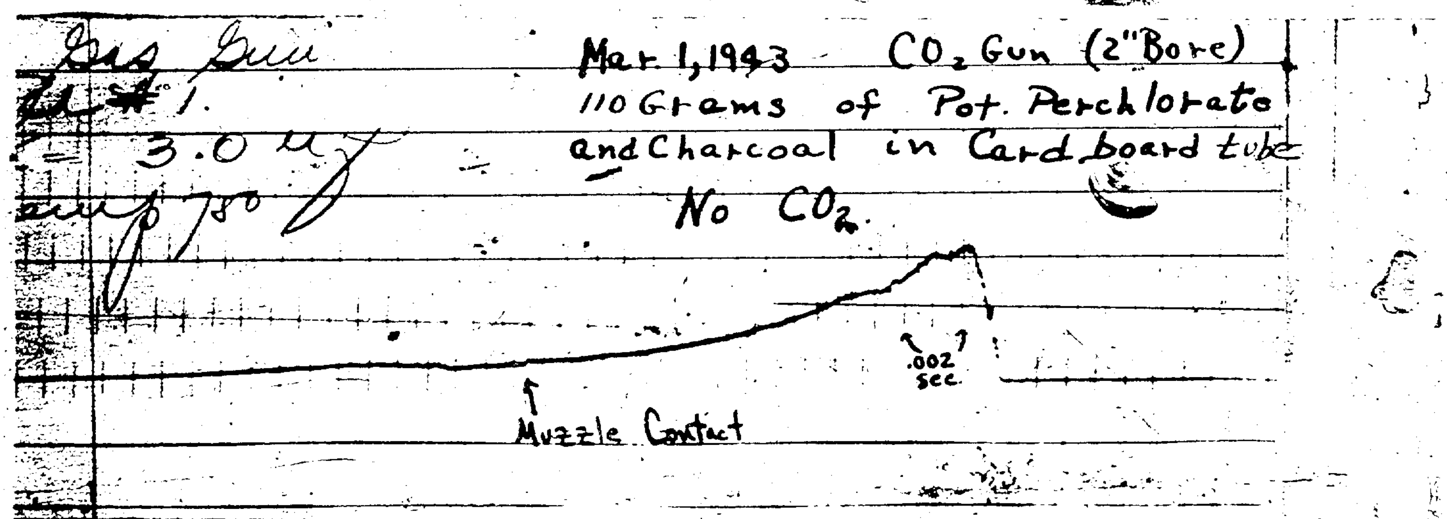

Gun Round No.1295
155 m/m Howitzer M 1918 No.1509
Powder Charge:8.5 Lbs of 3475
Projectile Wt.: 95 Pounds
Solenoid Muzzle Vel.:1038 F/S
Copper Press.:13,400 Piezo Press.14,600

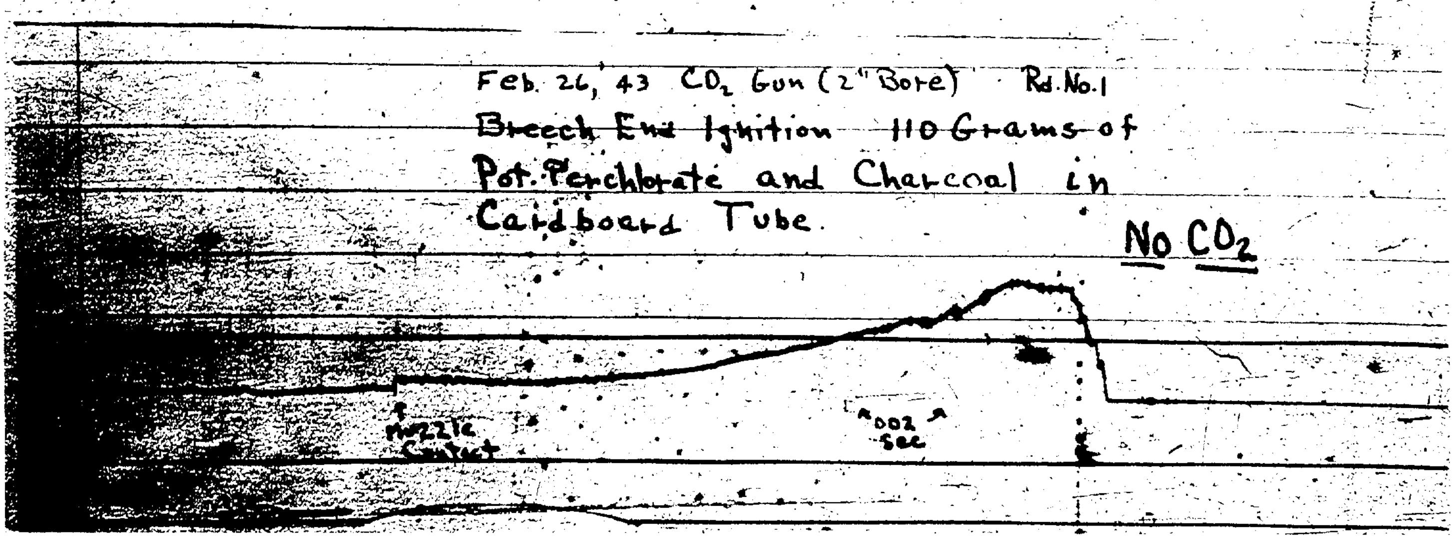

FEB. 25, '43 CO_2 GUN (2" BORE) ROUND #1
1.5 lb CO_2
5 lb SMOOTH-BORE SLUG
FRONT END IGNITION, 85 GRAMS OF POT. PERCHLORATE AND CHARCOAL IN STEEL TUBE
MUZZLE CONTACT
.002 SECOND


FEB 19, '43 CO_2 GUN (2" BORE) ROUND No. 5
BREECH END IGNITION 50 GRAMS OF POT. PERCHLORATE AND CHARCOAL IN CARDBOARD TUBE
MUZZLE CONTACT
ARRANGED AND FIRED BY Dr. Getz of the Cardox Corp.
.002 sec.


FEB 24 '43 CO_2 GUN (2" BORE) ROUND #1
1.5 lb. CO_2
5 lb SMOOTH-BORE SLUG
FRONT END IGNITION, 65 GRAMS OF POT. PERCHLORATE AND CHARCOAL IN STEEL TUBE
MUZZLE CONTACT
.002 SECONDS


FEB. 20, '43 CO_2 GUN (2" BORE) ROUND #1
1.5 lb. CO_2
5 lb. SMOOTH BORE SLUG
BREECH END IGNITION 110 GRAMS OF POT. PERCHLORATE AND CHARCOAL IN CARDBOARD TUBE.
.002 SECOND


Mar. 1, 1943 CO_2 Gun (2" Bore)
110 Grams of Pot. Perchlorate and Charcoal in Card board tube
No CO_2.
.002 sec.
Muzzle Contact


Feb. 26, '43 CO_2 Gun (2" Bore) Rd. No. 1
Breech End Ignition 110 Grams of Pot. Perchlorate and Charcoal in Cardboard Tube.
No CO_2
Muzzle Contact
.002 sec

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1. References:

a. BRL Report 339, "On the Use of CO_2 as a Propellant in Guns", by J. H. Frazer and J. R. Lane, March 1943, UNCLASSIFIED.

b. BRL Report ~~391~~ 343, "Heats of Explosion of Nitrocellulose in Indifferent Atmospheres (Part 1 of Mechanism of Powder Burning)", by J. H. Frazer and C. P. Fenimore, August 1943, UNCLASSIFIED.

c. BRL Report 353, "Report on Temperature Dependence on Rocket Behavior," by J. H. Frazer et. al., May 1943, UNCLASSIFIED.

d. BRL Report 465, "Experiments on Ignition of Nitrocellulose", by C. P. Fenimore and J. H. Frazer, May 1944, UNCLASSIFIED.

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