<table>
<thead>
<tr>
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<tr>
<th><strong>AD NUMBER</strong></th>
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<tr>
<th><strong>NEW LIMITATION CHANGE</strong></th>
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<tr>
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<td>Approved for public release, distribution unlimited</td>
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<tr>
<th><strong>FROM</strong></th>
</tr>
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<tr>
<td>Distribution authorized to U.S. Gov’t. agencies and their contractors; Administrative/Operational Use; 12 Mar 1943. Other requests shall be referred to U.S. Army Ballistic Research Lab., Aberdeen Proving Ground, MD.</td>
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</tbody>
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<th><strong>AUTHORITY</strong></th>
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<td>USARDEC ltr, 12 Oct 2004</td>
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**THIS PAGE IS UNCLASSIFIED**
ON THE USE OF CO, AS A PROPELLANT IN GUNS
ON THE USE OF CO₂ AS A PROPELLANT IN GUNS

Abstract

A thorough study of the possibilities of using CO₂ as a propellant in guns was made. The work was divided into two phases: (1) the use of solid CO₂ in addition to FMH powder in rifled guns. (2) The use of liquid-vapor CO₂ under pressure either alone or with a heater for un rifled guns. In the first case, the effect of the addition of solid CO₂ resulted mainly in the reduction of the muzzle velocity - even more than if an inert material had been used instead of the solid CO₂. In the second case, the heater used as propellant without CO₂ gave a smoother, more constant pressure-time curve than with the CO₂ but the pressure-time curve obtained with service propellant powder in other guns is much smoother than any obtained in those firings.

The Chief of Ordnance requested the Ballistic Research Laboratory to make a thorough study of the feasibility of using CO₂, either in the solid or liquid form, as a propellant for rifled or un rifled guns.

The first project 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 CO₂ for propellant increment charges in some zoned weapon, preferably a locomotive. Firing was started with solid CO₂ because it was the most readily available form of CO₂.
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:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Charge</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>10.64</td>
<td>650</td>
</tr>
<tr>
<td>II</td>
<td>12.68</td>
<td>710</td>
</tr>
<tr>
<td>III</td>
<td>15.14</td>
<td>780</td>
</tr>
<tr>
<td>IV</td>
<td>18.60</td>
<td>875</td>
</tr>
<tr>
<td>V</td>
<td>24.14</td>
<td>1020</td>
</tr>
<tr>
<td>VI</td>
<td>32.30</td>
<td>1235</td>
</tr>
<tr>
<td>VII</td>
<td>46.30</td>
<td>1550</td>
</tr>
</tbody>
</table>

The first phase of the CO₂ program consisted of substituting equal weights of solid CO₂ for removed organic propellant powder. The organic propellant powder was the service smokeless, Flashless, non-hygrosopic type of propellant.

The two howitzers chosen for the CO₂ 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

<table>
<thead>
<tr>
<th>Rd. No.</th>
<th>Base Charges</th>
<th>Increment Charge</th>
<th>CO₂ Charge</th>
<th>Muzzle Vel.</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FNH Lot 5632</td>
<td>FNH Lot 5632</td>
<td>oz.</td>
<td>f/s</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>11 oz.</td>
<td>9 oz.</td>
<td>0</td>
<td>955</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11 &quot;</td>
<td>9 &quot;</td>
<td>0</td>
<td>954</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11 &quot;</td>
<td>5 &quot;</td>
<td>4</td>
<td>811</td>
<td>Pulverized CO₂ in paper bag ahead of primer</td>
</tr>
<tr>
<td>4</td>
<td>11 &quot;</td>
<td>5 &quot;</td>
<td>4</td>
<td>794</td>
<td>Pulverized CO₂ mixed with increment powder</td>
</tr>
<tr>
<td>5</td>
<td>11 &quot;</td>
<td>5</td>
<td>0</td>
<td>816</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>11 &quot;</td>
<td>5</td>
<td>0</td>
<td>843</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>11 &quot;</td>
<td>2</td>
<td>7</td>
<td>688</td>
<td>Pulverized CO₂ mixed with increment powder</td>
</tr>
<tr>
<td>8</td>
<td>11 &quot;</td>
<td>2</td>
<td>7</td>
<td>668</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>11 &quot;</td>
<td>0</td>
<td>9</td>
<td>660</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>11 &quot;</td>
<td>0</td>
<td>9</td>
<td>642</td>
<td></td>
</tr>
</tbody>
</table>

### 75mm Pack Howitzer Firings

<table>
<thead>
<tr>
<th>Rd. No.</th>
<th>Base Charges</th>
<th>Increment Charge</th>
<th>CO₂ Charge</th>
<th>Muzzle Vel.</th>
<th>Piezo-electric Press.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FNH Lot 5638</td>
<td>FNH Lot 5638</td>
<td>oz.</td>
<td>f/s</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>6.0 oz.</td>
<td>9.0 oz.</td>
<td>0</td>
<td>1743</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6.0 &quot;</td>
<td>6.0</td>
<td>0</td>
<td>1742</td>
<td>21,000 lb/in²</td>
</tr>
<tr>
<td>3</td>
<td>6.0 &quot;</td>
<td>5.0</td>
<td>2.0</td>
<td>936</td>
<td>13,350 &quot;</td>
</tr>
<tr>
<td>4</td>
<td>6.0 &quot;</td>
<td>5.0</td>
<td>4.0</td>
<td>932</td>
<td>10,200 &quot;</td>
</tr>
<tr>
<td>5</td>
<td>6.0 &quot;</td>
<td>2.0</td>
<td>7.0</td>
<td>758</td>
<td>10,750 &quot;</td>
</tr>
<tr>
<td>6</td>
<td>6.0 &quot;</td>
<td>2.0</td>
<td>7.0</td>
<td>724</td>
<td>7,500 &quot;</td>
</tr>
<tr>
<td>7</td>
<td>6.0 &quot;</td>
<td>2.0</td>
<td>9.0</td>
<td>699</td>
<td>9,600 &quot;</td>
</tr>
<tr>
<td>8</td>
<td>6.0 &quot;</td>
<td>2.0</td>
<td>9.0</td>
<td>678</td>
<td>10,900 &quot;</td>
</tr>
<tr>
<td>9</td>
<td>6.0 &quot;</td>
<td>2.0</td>
<td>9.0</td>
<td>701</td>
<td>9,800 &quot;</td>
</tr>
<tr>
<td>10</td>
<td>6.0 &quot;</td>
<td>2.0</td>
<td>9.0</td>
<td>690</td>
<td>8,700 &quot;</td>
</tr>
</tbody>
</table>
An inspection of these tables shows the effect of the replacement of propellant powder by \( \text{CO}_2 \). 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 \( \text{CO}_2 \) and sixteen were service powder. The velocity dropped from the 955 f/s and 974 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 \( \text{CO}_2 \) 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 \( \text{CO}_2 \); 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 \( \text{CO}_2 \) and 16 oz. of service powder (Rds. 7-8) gave a velocity lower by 29 f/s than the two rounds (Rds. 5-6) without any \( \text{CO}_2 \) and with 16 oz. of service powder. Firing thirteen ounces of service powder plus seven ounces of \( \text{CO}_2 \) gave velocities of 633 f/s and 685 f/s while a charge of 11 ounces of service powder plus nine ounces of \( \text{CO}_2 \) gave velocities of 850 f/s and 648 f/s. It is apparent from these results that solid \( \text{CO}_2 \) is not a suitable substitute for service propellant 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 \( \text{CO}_2 \) reduced the velocity by 329 f/s to 919 f/s and 922 f/s (Rds. 3-4). Another reduction of three ounces in weight of service powder with the corresponding addition of three ounces of \( \text{CO}_2 \) further reduced the velocity to 773 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 \( \text{CO}_2 \) were added the velocities were 693 f/s and 675 f/s (Rds. 7-8) while without the \( \text{CO}_2 \) the velocities were 771 f/s and 709 f/s (Rds. 9-10).

It is evident from these results that the solid \( \text{CO}_2 \) required an equivalent amount of propellant powder not only to give equal velocity, but even a velocity lower than that obtained by using the \( \text{CO}_2 \) completely. Any inert material like air (such as ammonia or carbon) would have increased the velocity and that obtained by the propellant alone. In solid \( \text{CO}_2 \), both because of its low temperature and high specific heat and the heat of vaporization, reduces the velocity.
A program of firings with liquid CO₂ 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 CO₂.

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 CO₂ 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:

<table>
<thead>
<tr>
<th>Gun</th>
<th>Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ (2&quot; Bore)</td>
<td>61 calibers</td>
</tr>
<tr>
<td>75mm Pack Howitzer</td>
<td>13 calibers</td>
</tr>
<tr>
<td>105mm Howitzer</td>
<td>20 calibers</td>
</tr>
</tbody>
</table>

It is evident that this CO₂ 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" n.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 maneuverability end 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. E. 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 (K Cl O₇) and Charcoal (C). The Cardox cartridge is then filled with liquid-va or CO₂. Then used for blasting coal, the heating mixture (CO₂ and C) is ignited by the electric match and the pressure built up by the heated CO₂ bursts the blow-out disc and the CO₂ 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 Fred 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 30 feet, which
corresponds to a velocity of about 300 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 80° F will be 2.5 times that when the air
temperature is 20° F. This variation in pressure causes a
variation in range, 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
combustion reactor. 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:

<table>
<thead>
<tr>
<th>Charge</th>
<th>Max. Pressure</th>
<th>Velocity (at 45°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 grams heater</td>
<td>+1.5 lb. CO₂</td>
<td>3290 lb/in²</td>
</tr>
<tr>
<td>110 ° ° 1.7</td>
<td>9360 °</td>
<td>756</td>
</tr>
<tr>
<td>110 ° ° No. CO₂</td>
<td>7130 °</td>
<td>869</td>
</tr>
<tr>
<td>110 ° °</td>
<td>6520 °</td>
<td>Lost</td>
</tr>
</tbody>
</table>

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 CO₂ 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. Henner, 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 flamed 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 the pressures and velocities obtained on these grounds.

<table>
<thead>
<tr>
<th>Charge</th>
<th>Max. Press.</th>
<th>Velocity (at 45°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65 gm heater + 1.54 lb. CO₂</td>
<td>4280 lb/in²</td>
<td>646 f/s</td>
</tr>
<tr>
<td>15 gm heater + 1.50 lb. CO₂</td>
<td>640 lb/in²</td>
<td>486 f/s</td>
</tr>
</tbody>
</table>

For comparison, there is attached a pressure-time curve obtained in a 12gmm Hiwitzer firing organic propellant 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 CO₂ cannot be fired without a blow-out pressure disc. Such an arrangement that is a copper blow on the base of the projectile, even then a relatively low pressure disc was used. Once one occasion, the sheds can discharge 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 CO₂ (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 CO₂. Since it is necessary to withstand a pressure up to 10,000 lb/in² the cartridge containing the liquid CO₂ must be fairly substantial. The empty Cardox cylinder weighed about seventeen pounds, while the cartridge case and powder for the 75mm Pack Howitzer weigh only about three pounds.

If solid CO₂ were used, the transportation problem would be quite difficult. The solid CO₂ 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 CO₂ and liquid CO₂. No attempt was made to use gaseous CO₂ introduced into a cartridge case under pressure. The difficulties of obturating such a system (cartridge case and projectile) are obvious. In addition, the CO₂ would be definitely inferior to other gases since it is a triatomic molecule with a polar heat greater than that of the powder gases. It follows that heat would be absorbed in heating the CO₂ and the resultant partial pressure of this heated CO₂ 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 CO₂ would have a higher temperature for the corresponding pressure than the powder gases without the CO₂ or powder gases mixed with gases of smaller polar heat than CO₂.

**CONCLUSION:**

1. Solid CO₂ added to propellant powder performs no useful function.

2. Liquid-vapor CO₂ alone is not feasible in guns because the vapor pressure is a rapidly varying function of the temperature of the CO₂. This results in the velocity and the range both being rapidly varying function 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 propellant 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
PROGRAM FOR CO₂ GUN

On February 2nd after the firing of the 75mm and 105mm howitzers using CO₂ in addition to PVA powder as propellant, a conference was held in Colonel Simon's office to discuss the further applications of CO₂ 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. Konner

At this conference a program was drawn up and agreed upon by the conference as the most likely to yield results upon which to judge the practicability of using CO₂ as a propellant. It was agreed by everyone that the advantage of using CO₂ 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 CO₂ (liquid) alone bursting a blow-out disc either mechanically or by a small charge of high explosive. This disc to be placed between the CO₂ container and the gun tube.

(2) Fire a standard Cardox mine cartridge containing CO₂ (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 heater of gun in a metal 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 1 ½ lb. The tube was to be a smooth bore.

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

J. P. Lane.
Gun Pound 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 CO₂ Gun (2" BORE) Round #1 1.5 lb CO₂
5 lb Smooth-Bore Slug

Front End Ignition, 85 grams of
Pot. Perchlorate and Charcoal in
Steel Tube

↑ Muzzle Contact 0.002 second

FEB. 19, '43 CO₂ 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. Pat of the
Cardox Corp.

FEB. 24, '43 CO₂ Gun (2" BORE) Round #1 1.5 lb CO₂
5 lb Smooth-Bore Slug

Front End Ignition, 65 grams of
Pot. Perchlorate and Charcoal in
Steel Tube

↑ Muzzle Contact 0.002 seconds
FEB. 20, 43 CO₂ Gun (2" Bore) Round #1
Breech End Ignition 110 grams of
Pot. Perchlorate and Charcoal in
Cardboard Tube.

Mar 1, 1943 CO₂ Gun (2" Bore)
110 Grams of Pot. Perchlorate
and Charcoal in Cardboard Tube
No CO₂

Muzzle Contact

Feb 26, 43 CO₂ Gun (2" Bore) Rd. No. 1
Breech End Ignition 110 Grams of
Pot. Perchlorate and Charcoal in
Cardboard Tube. No CO₂
MEMORANDUM FOR Defense Technical Information Center,  
ATTN: DTIC-BCS, 8725 John J. Kingman Road,  
Suite 0944, Ft. Belvoir, VA 22060-6218

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1. References:
   a. BRL Report 339, "On the Use of CO₂ as a Propellant in Guns", by J. H. Frazer and J. R. Lane, March 1943, UNCLASSIFIED.

2. Subject matter experts and the Army Research Laboratory Security/CI Office have determined that the referenced reports may be released to the public. Request that you mark all of your copies of the documents with the following distribution statement:

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3. Questions should be directed to Mr. Douglas J. Kingsley, telephone 410-278-6960.

DAVID W. ORE
Manager
Experimental Support Group