TECHNICAL REPORT ARLCB-TR-79037

POTENTIAL EROSION RESISTANT REFRACTORY METAL (AND/OR) ALLOY COATINGS FOR GUN TUBES

I. Ahmad
P. Greco
G. D'Andrea
J. Barranco

December 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

AMCMS No. 611102H600011

DA Project No. 1L161102AH60

PRON NO. GG825497GGM7

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacturer(s) does not constitute an official indorsement or approval.

DISPOSITION

Destroy this report when it is no longer needed. Do not return it to the originator.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER ARLCB-TR-79037	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Potential Erosion Resistant Refractory Metal (and/or) Alloy Coatings for Gun Tubes	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) I. Ahmad, G. D'Andrea, P. Greco, J. Barranco	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Benet Weapons Laboratory Watervliet Arsenal, Watervliet, N.Y. 12189 DRDAR-LCB-TL	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS No 611102H 600011 DA Project NO.1L161102AH60 Pron No. GG825497GGM7
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research and Development Command Large Caliber Weapon System Laboratory Dover, New Jersey 07801	12. REPORT DATE Dec 1979
	13. NUMBER OF PAGES 14
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Presented at Tri-Service Conference on Corrosion, New Orleans, La., Oct. 1978.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Erosion Resistant Materials
Coatings
Gun Barrel Erosion
Refractory Metals
Wear

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

This report addresses the problem of erosion in gun tubes and the need to develop superior materials and techniques for its control in gun barrels.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

POTENTIAL EROSION RESISTANT REFRACTORY METAL (AND/OR) ALLOY COATINGS FOR GUN TUBES

I. Ahmad, P. Greco, G. D'Andrea, and J. Barranco
U. S. Army Armament Research and Development Command
Benet Weapons Laboratory, LCWSL
Watervliet Arsenal, Watervliet, NY 12189

At the 1972 Triservice Meeting on Corrosion one of the authors reviewed the problem of erosion and corrosion in gun tubes and emphasized the need for R&D not only to understand this complex phenomenon, but also to develop superior materials and techniques of application in gun barrels for its control. At that time very limited R&D activity existed in the DoD laboratories in this area. It is heartening to see that since then, there is increasing awareness of the problem and some real action has been taken by various agencies. For example, during the last two years in the ARRADCOM the Large Caliber Systems Lab has developed a well coordinated program on erosion. In this paper some of the work that is in progress at Benet Weapons Lab on the evaluation of refractory metal coatings will be discussed. The paper is divided in three parts, (1) Brief introduction to the nature and causes of erosion; (2) Requirements of an ideal erosion resistant material; and (3) Work at the Benet Weapons Lab.

Nature And Causes Of Erosion

Erosion can be defined as the progressive damage of bore surface and its enlargement as a result of normal firing, which ultimately causes loss of muzzle velocity, range and accuracy, and therefore effectiveness of the weapon. Figure 1 shows a view of new and eroded 105 mm M68 barrel. In general, erosion is more severe in the origin of rifling area, and the barrel is condemned when the bore diameter is enlarged in the region beyond a prespecified limit, for example, 0.075 in. for 105 mm M68. Figure 2 shows a typical erosion profile of an unplated tube in which M490 HT rounds (without additives) have been fired. The tube is condemned after 100 rounds. The erosion decreases down the bore toward the muzzle end. Figure 3 summarizes the conditions to which the bore surface of a barrel is exposed on firing. Interaction of three major elements are involved in erosion: (1) Gun steel at the bore. The composition and properties are given in Table 1. (2) The propellant. In advanced barrels usually double or triple base propellants are used, which have isochoric flame temperatures of 3000°K or higher. The combustion gases consist of CO, CO_2, H_2, H_2O, N_2 and smaller quantities of NH_3, CH_4, H_2S, NO and a number of other gaseous species. (3) The projectile, which has a rotating band, normally made of pure copper or gilding metal.

Reprinted from Proceedings of the 1978 *Tri-Service Conference on Corrosion,* MCIC Report/MCIC-79-40, May 1979.

TABLE 1. TYPICAL COMPOSITION AND PROPERTIES OF GUN STEEL

Composition (wt %): 0.37C, 0.47Mn, 0.006P, 0.01S, 0.02Si 3.17Ni, 0.85Cr, 0.65Mo, 0.10V, Balance Fe.

Physical Metallurgy	Tempered Martensite
Yield Strength	140-160 Ksi
V-Notched Charpy Impact Strength	30 ft. lb.
Hardness	38 Rc
m.p.	1450°C
Latent Heat of Fusion	3.6 Kcal/mole
Coeff. of Thermal Expansion	15×10^{-6} cm/cm/°C
Thermal Conductivity	0.184 cal/cm^2/cm/sec/°C

When the gun is fired the propellant burns and it develops high temperatures (2500-3000°K) and high pressure (30-80 Ksi) due to the formation of large volume of gases which propel the projectile. Under this pressure the rotating band engages the rifling, developing engraving stress as high as 50 Ksi, and as it travels a few inches from the O.R. (origin of rifling) the temperature at the rotating band-bore surface interface is high enough to melt the band surface, providing hydrodynamic lubrication to the projectile which acquires the requisite velocity as it emerges at the muzzle.

Heat is transferred from the gases to the bore surface by forced convection, raising the few mils of the surface in the O.R. area to 800-1300°C. This induces martensite→austenite and α-γ transformation. Simultaneously there is interaction of combustion gases which convert the surface to carbides and oxides, while some C and N diffuses deeper in the heat effected zone, stabilizing some of the austenite phase. With single base propellants Fe_3C is the predominant product, while with double base high temperature propellant, FeO is the major product. This altered region (Figure 4) therefore consists of the top 'white layer', an inner 'white layer' and then the thermally altered layer. Its composition and nature has been the subject of many reviews (1-4). Here, it is sufficient to say these reaction products melt around 1150°C. Therefore, particularly in advanced barrels in which high temperature propellants are used, the surface material melts and is removed by the high velocity gases. Repeated firing causes thermal fatigue of the surface, which cracks (called heat checking). This surface damage is further aggravated by the dilation of the tube due to pressure and engraving stresses, which makes more surface available for thermo-chemical interaction in subsequent firings. From this brief description, it will be apparent that erosion in gun barrels is caused essentially by the following factors.

1. Thermal including chemical.
2. Mechanical.

Therefore to reduce erosion, the following methods of control become obvious.

a. Reduce bore surface temperature by using low flame temperature, less erosive propellants, or employ other means, such as TiO_2 + wax additive or dimethylsilicone ablative to generate cool gaseous interface between high temperature combustion gases and the bore surface. External cooling has also been used.

b. Reduce engraving stresses by using plastic bands or improve rifle design.
c. Use materials at the bore surface, which are resistant to all these conditions, i.e., thermal, chemical and mechanical. Description of the first two measures is outside the scope of this paper. Therefore in the following the potential of the third measure is discussed.

Requirements Of An Ideal Erosion Resistant Material

Since the successful casting of steel barrels by Krupps in the 19th century, gun steel has been reigning as the best material for all types of guns. It has been modified in composition or by thermomechanical treatments, but has never been replaced. However, as early as World War II, it was recognized that while it worked well in barrels iwth conventional ballistics, with barrels designed for high muzzle velocity or rate of fire and extended range, as high temperature propellants had to be used, steel because of its low m.p. and low yield strength at high temperatures was simply unsuitable and must be protected with a suitable high temperature-high strength material in the form of coating or liner.

During 1940-45, systematic and exhaustive work was done under the sponsorship of the National Defense Research Committee and a large number of materials too numerous to cover under this review, were evaluated. After the war some more materials were screened by using a number of techniques including erosion vent plugs.

One of the major outcomes of the 1940-45 studies was the identification of Stellite 21, which is a cobalt base alloy, as an excellent erosion resistant material, with optimum hot hardness and ductility and good fabricability. Liners made of Stellite 21, are still being used in M60 machine gun barrels. One of the major drawbacks of this alloy is its low m.p. (about 1280°C). When high temperatuer propellants are used, it fails by surface melting. Chromium is excellent erosion resistant material and has been used with significant success as a coating applied in gun barrels by relatively cheap electroplating process. Unfortunately, it is brittle, and cracks and chips off on firing. During the war, a number of chrome alloys were formulated and evaluated. The best was Cr-25 Fe-15MO. It had excellent erosion resistance. Liners of this alloy inserted by shrink fitting (shrink fit pressure 90-10,000 psi) in 0.5 cal barrel showed less erosion than stellite even after 3800 rounds. Nevertheless, it also has undesirable brittleness. Molybdenum hardened with 0.1% Co is another alloy which was found to have excellent erosion resistance. However, the technology of fabrication of its liners was not well developed at that time. The liners failed usually by cracking. Since World War II, a number of new alloys of Ta, Cb, W and Mo have been screened by erosion vent plug techniques. Some of these materials such as Ta, Ta-10W and Cb coextruded in 7.62 mm barrels were also evaluated by test firing. Ta-10W was found to perform the best in small caliber guns. Cb, because of its low hardness, showed swaging of lands. Tungsten, used as a coating applied by CVD, cracked like chromium.

Table 2 lists the material which have been found to have the highest promise so far. A critical assessment of the conditions present in the gun barrel on firing and the performance of the materials given in this table indicates a number of essential criteria of erosion resistant materials, which are summarized in Table 3.

TABLE 2. SOME MATERIALS WITH DEMONSTRATED EROSION RESISTANCE

m.p. 1050°C or less:	steel, stellite-21
m.p. above 1500°C:	chromium and Cr-Mo-Fe alloys molybdenum (0.1% Co) tungsten and tungsten alloys tantalum and tantalum alloys (Ta-10W) columbium and columbium alloys

TABLE 3. CRITERIA OF AN IDEAL EROSION RESISTANT MATERIAL

	Barrel	Liner	Coatings
m.p.	High >1500°C	High >1500°C	High >1500°C
Yield strength at high temperatures	High	High	High
Elastic modulus	High	Compatible with the jacket (same or lower preferred)	Compatible with the substrate (same or lower preferred)
Fracture toughness and impact strength	High	High	High
Hot Hardness	High (appropriate)	High (appropriate)	High (appropriate)
Chemical resistance to propellant gases	High	High, unless used as sub-strate for a coating	High
Coefficient of thermal expansion	Low	Compatible with the jacket	Compatible with the substrate
Thermal conductivity	High	Low	Low
Reaction with rotating band	Inert	Inert, unless protected with a coating	Inert
Phase transitions	None	None	None

A material with all these requirements is hard to find. However, it is not hard to recognize that the probability of finding an optimum material is in the refractory metal (or alloy) group.

The refractory metals in Table 2 can be divided into two classes: (1) with elastic modulus higher than steel i.e., chromium molybdenum, and tungsten and (2) elastic modulus lower than steel, i.e., tantalum and columbium. In the first class all the metals show good erosion resistance, when evaluated by erosion vent plug techniques, but when applied as liners or coatings in gun steel barrels, they failed usually by cracking. In the second class, these materials did not do as good as those in the first class in terms of gas erosion, but when applied as liners they behaved very well, except that they showed land swaging. This can be explained by referring to Figure 5 which shows idealized stress-strain curves for the refractory metals. It shows that at the strain developed during firing the Class I materials because of their high elastic modulus, depending upon the coating or liner thickness, experience much higher stress than steel, and do not effectively transfer the load to the substrate (jacket). Therefore, if the material is brittle, such as Cr and W, it will crack. In the past, Mo liners were usually made by forging. Due to anisotropy they had poor transverse strength and therefore under firing stresses, they also cracked. Thermal mismatch further aggravates this problem. The reason why chromium did show some successful performance, was that the electroplated chrome has a modulus close to that of steel. In any case, coatings and liners of these materials can perform successfully, only if they are placed under a compressive stress. The low elastic modulus metals such as tantalum and columbium assure effective load transfer from the coating/liner to the jacket, and they are also relatively ductile. These factors contributed to their reported successful performance. Compared with Class I material, they also have much lower ductile-brittle transition temperature.

Hot hardness is another critical requirement. The coating/liner must effectively resist the swaging action of the projectile. The reason of the success of stellite 21, as compared with steel which has a higher m.p., is that stellite maintains its hardness to temperatures at least 250°C higher. Refractory metals like TZM, Ta-10W maintain hardness even to higher temperatures. Hence these are the materials which have the potential for resisting erosion in future high temperature, hypervelocity barrels. Most of the refractory metals are either expensive (like Ta, Cb) or are imported (W and Cr). Only Mo is in good supply and is relatively cheaper. Therefore, for economic reasons, these metal/alloys will have to be used either as liners or coatings.

Work At Benet Weapons Laboratory

Of these materials, the most advanced technology is that of the chromium which can be applied by electroplating from aquous electrolytes. The technology of refractory metals has also advanced considerably since World War II. Therefore, at Benet Weapons Laboratory, R&D programs are in progress under two distinct areas.

Short Range Solution

Improvement of conventional chrome plating process, applying it in large caliber guns, and evaluating by test firing.

Long Range Solution

Development of advanced technology of refractory metal coatings and liners by working initially with 20 mm guns, and later applying it to advanced large caliber guns.

Chrome Plating

Chrome plating has shown significant improvement of the life and performance of small caliber guns. In the large caliber guns, until recently, no systematic studies to optimize the process, and coating parameters such as thickness, bond strength, substrate requirements, surface finishes, etc., have been made. Work is now in progress on these lines at Benet Weapons Laboratory. We have shown that in 105 mm M68 gun 5 mil Cr chips off after 100 rounds, while 10 mil thick coating stays in the O.R. even after firing 430 490HT rounds (without additives). There is only minor chipping as shown in Figure 6. The ercsion profile of the gun after 500 rounds is included in Figure 2, which illustrates the beneficial action of chromium. In this tube chromium was plated in partial length (30 inches from O.R.), with the idea that beyond that point, down the bore, because of reduced temperature and pressure, chrome plating was unnecessary. To prove this point further, currently two partial plated and two full plated tubes are being evaluated by test firing. Similar work on the coating of 155 mm M199 tube has shown the enhancement of the tube life from 1500 rounds to 2300 rounds. Figure 7 shows the erosion profile of unplated and plated tubes. But the conventional chromium, which is of high contractile (HC) type, is very brittle and has microcracks in the as plated condition, do unavoidably cracks and chips off in some sections. Figure 8, shows the origin of rifling and down bore section of chrome plated 155 mm M199 tube before and after firing 250 rounds. We are investigating the critical causes of this condition. It is now recognized that in order for chromium coating to perform satisfactorily, and stay on the bore surface it is necessary that (a) the coating should be thick enough to protect the substrate from the heat effects (softening and phase transformation), (b) should have no built in microcracks and (c) should have some deformibility so that it does not crack due to mechanical fatigue or thermal shock. Low contractile (LC) chromium which has fewer microcracks than HC and is denser and softer, appears to have some promise. This is currently being evaluated in our laboratory. Crack-free chrome can be obtained by using special electroactive additives in the conventional chrome bath. Another approach which has shown some interesting results, is the laser treatment which not only heals the microcracks in HC chromium coating and softens it, but also increases the hardness of the substrate.

It is hoped that these programs will lead to a chrome plate which will have superior performance than that of conventional HC coating in the large caliber guns.

Tantalum Coating

For long range solution, tantalum coating was selected for investigation as a possible control measure. It can be applied by three processes namely: chemical vapor deposition, electrodeposition from fused salts and ion plating. Of these the fused salt process is the most advanced, but it requires the deposition temperature of 800°C. The barrel as such cannot be exposed to this temperature, because this will deteriorate the mechanical strength of gun steel. Therefore, it is necessary to apply the coating on a liner made of a suitable material, which can then be shrink fitted into the barrel. Stellite 21 was selected as a liner material, as it maintains its hardness up to 800°C, and if during firing it is exposed because of removal of coating, it would not erode badly.

Therefore 20 mm partial liners of stellite 21 (cast) and gun steel were electroplated with 5 mil thick Ta from a flinak bath at about 800°C. Metallographic examination of plated specimens show no visible interaction of Ta with steel, but a diffusion (or interaction) zone formed with stellite 21 substrate (Figures 9a,b). The liners were rifled before coating. After final mechanical finishing of the i.d. and o.d. of the liners, they were shrink fitted in the 20 mm M24A1 barrels. Adequate precalculated shrink fit pressure was applied to eliminate the movement of the liner due to the torque forces developed during firing. For control purposes two more barrels one with uncoated steel liner and the other with chromium plated steel liner were also fabricated. These barrels were test fired using a firing schedule consisting of 40 rd burst with 15 second cooling after each burst and complete cooling of the barrel after 200 rd. On the average 1100 rds were fired in each barrel. The barrel with Cr plated liner was fired about 500 rds. Details of this work will be reported by one of the authors in an ARRADCOM report in the near future. The wear curves are shown in Figure 10. From the metallographic examination, the major conclusions drawn from those tests were as follows:

1. Uncoated steel liner performed the worst. It developed the usual white layer with large areas of deformed and cracked surface (Figure 11a).
2. Tantalum coating swaged off from the hard stellite surface, which then eroded in the conventional manner. Like other stellite liners used in M60 machine guns, this liner was also found to shrink, which resulted in the removal of Ta in the early stages of the test.
3. Ta coated steel liner was the most encouraging. The steel substrate under the coating had annealed, and lost most of its strength (hardness R_a 15). On firing it mechanically deformed, along with the coating to a certain point, indicated by the enlargement of the bore in the O.R. area; but then it stabilized and there was no further noticeable erosion. In fact the coating looked polished after 1100 rounds. No heat checks on the surface were noted. Also there was no heat affected zone (compare with Figure 11a) under the coating.
4. Chrome coating though showed much smaller erosion up to 1100 rds, but it cracked and chipped off from origin of rifling area after 100 rounds. After a certain number of rounds, when the coating was badly damaged, the erosion in the O.R. increased abruptly.

From the above tests, it is clear that the plated lined barrels must have more rounds so that fair comparison with chromium plated lined barrels can be made. However, because of the relative ductility and high m.p. of tantalum, it can be expected that erosion rate of Ta will be very low even after 5000 rds. Obviously, there is a need to improve the properties of the coating and substrate to eliminate the deformation in the case of Ta-steel and sloughing off from the Ta-stellite liner system.

To improve the hardness of Ta, our studies have resulted in the successful codeposition of Cr with Ta from the fused salt bath. The hardness of Ta was found to increase with the increase of Cr as shown in Figure 12. At this time high temperature data are not available, but it is expected that Ta-Cr alloy coating will maintain its hardness at elevated temperatures also. Hopefully chromium will also improve the oxidation resistance of tantalum coating.

Our future plans include scaling up of the process to apply Ta coating in 105 mm guns, and also evaluate monolith refractory alloy liners. This of course requires a well coordinated multi-disciplinary approach to the problems, and needs considerable resources.

Summary

1. To meet the performance requirements of advanced large caliber guns, it is necessary to protect gun steel at the bore surface with refractory metal coatings or liners.

2. Although conventional HC chromium has shown significant improvement of the erosion life of 105 mm and 155 mm guns it is necessary to identify the critical conditions required to achieve its optimum performance, and overcome its inherent weakness of brittleness.

3. Because of its high m.p. and ductility, tantalum has shown very encouraging results as a coating in lined 20 mm M24A barrels, but much more work is necessary to obtain an optimum coating-substrate system, and then scale it up for application to 105 mm and 155 mm barrels.

References

(1) Burlew, J. S. (Editor), "Hypervelocity Guns and Control of Gun Erosion," Summary Technical Report NDRC Division 1, Office of Scientific Research and Development, Washington, D.C., 1976.

(2) Ahmad, I. and Picard, J. P., "Proceedings of the Triservice Technical Meeting on Gun Erosion and Control," Watervliet Arsenal, Watervliet, NY, 1970, AD No. 14668.

(3) Picard, J. P. and Ahmad, I., "Proceedings of the Triservice Gun Tube Wear and Erosion Symposium," ARRADCOM, Dover, NJ, March 29-31.

(4) Ahmad, I., "Physicochemical Aspects of Gun Barrel Erosion and Its Control," Proceedings of the Symposium on High Temperature Gas-Metal Reactions in Mixed Environments, Jasson and Foroulis (Editors), Boston, The Met. Soc. AIME, May 1972.

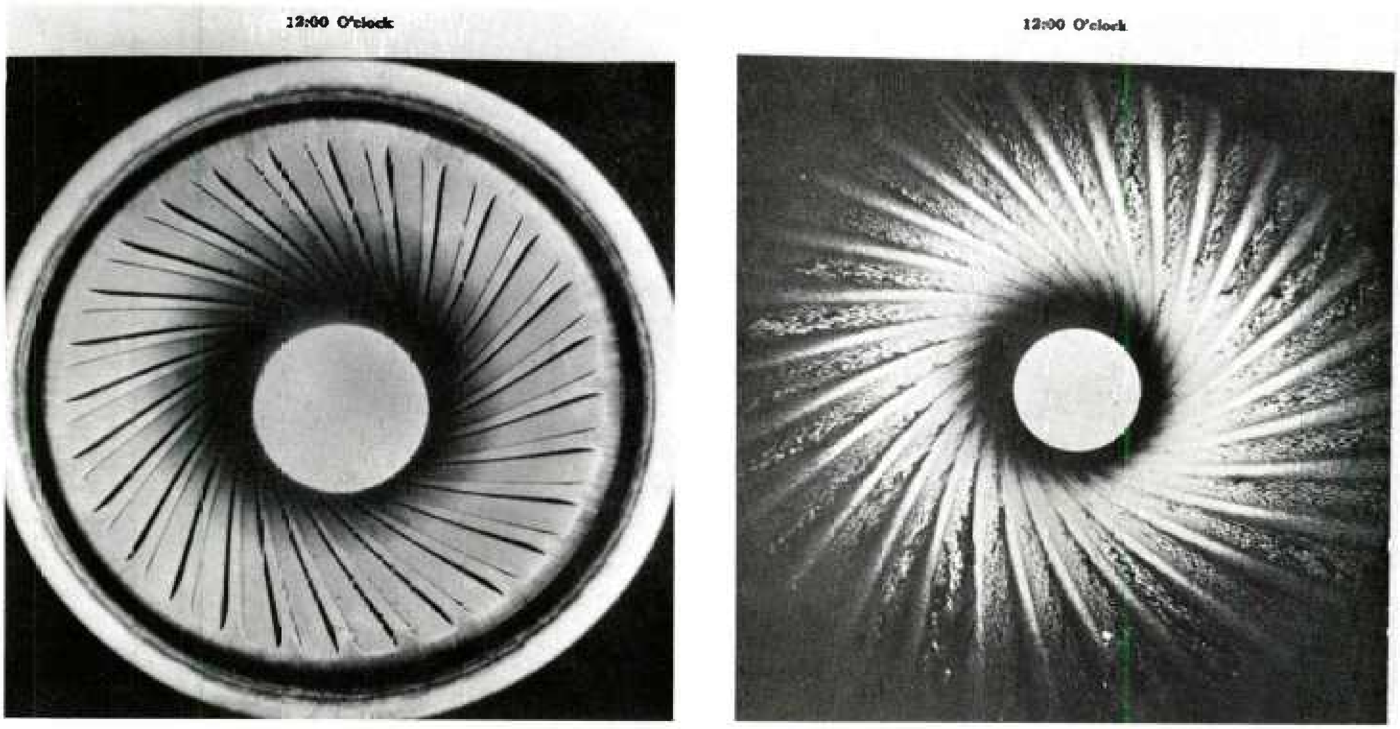

FIGURE 1. 105 MM M68 GUNS SHOWING CONDITIONS OF RIFLING AT ORIGIN OF RIFLING AFTER (A) 2 RDS AND (B) 1214 RDS.

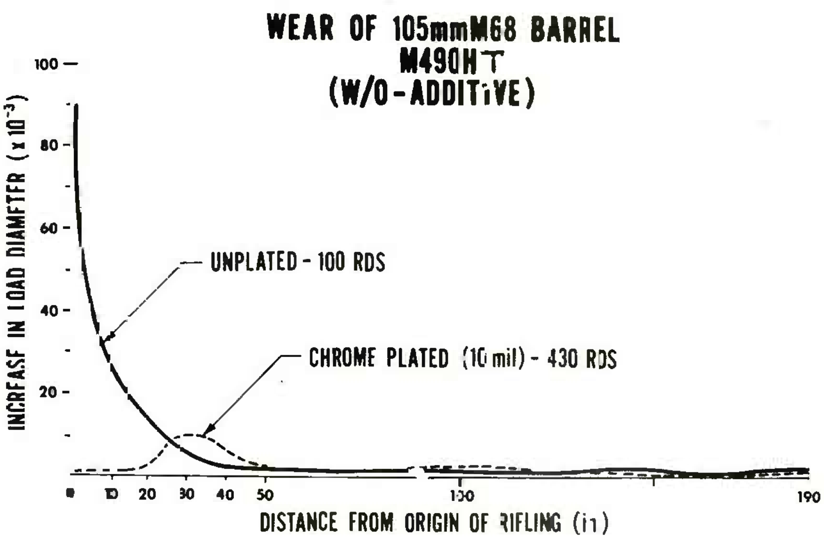

FIGURE 2. WEAR PROFILES OF UNPLATED AND PLATED 105 MM M68 TUBE.

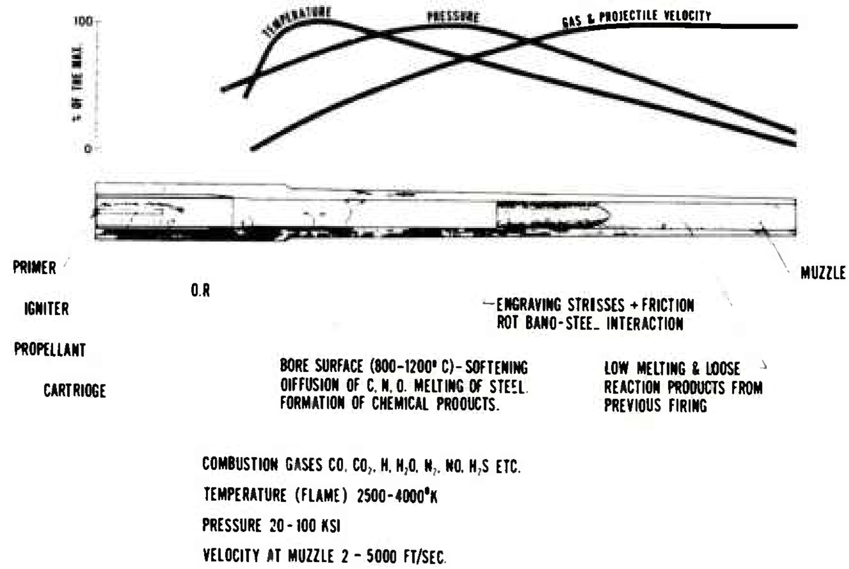

FIGURE 3. SCHEMATIC REPRESENTATION OF SALIENT CONDITIONS IN THE BARREL AT FIRING.

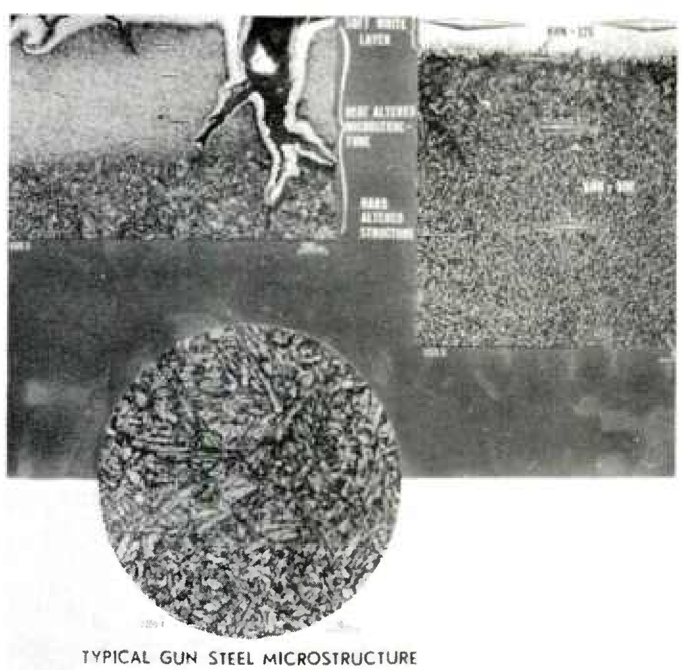

FIGURE 4. SECTION OF A TUBE AFTER FIRING, SHOWING 'WHITE' AND THERMALLY ALTERED LAYER. (COURTESY DR. M. KAMDAR).

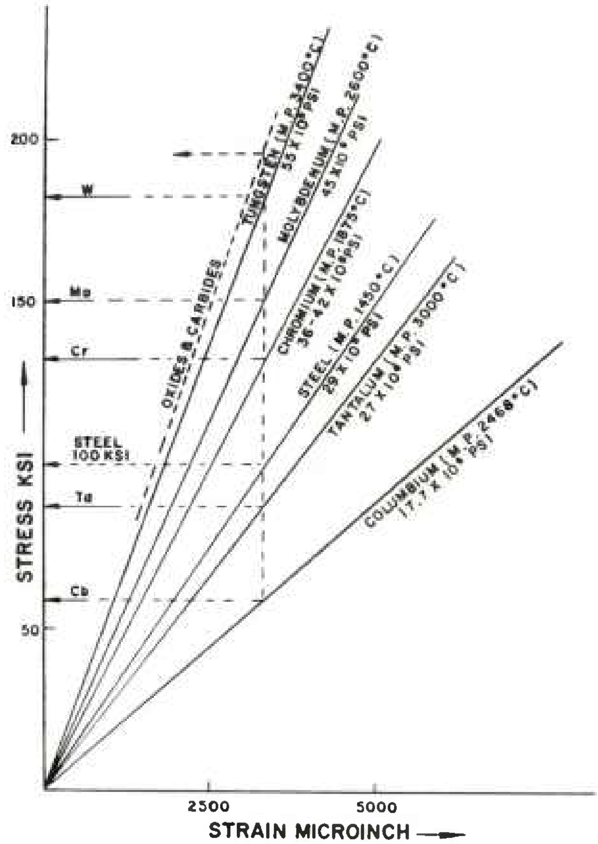

FIGURE 5. IDEALIZED STRESS STRAIN CURVES OF SOME REFRACTORY METALS AND GUN STEEL.

FIGURE 6. SHOWING O.R. OF 10 MIL CHROMIUM PLATED 105 MM TUBE AFTER 493 ROUNDS (COURTESY F. SAUTTER).

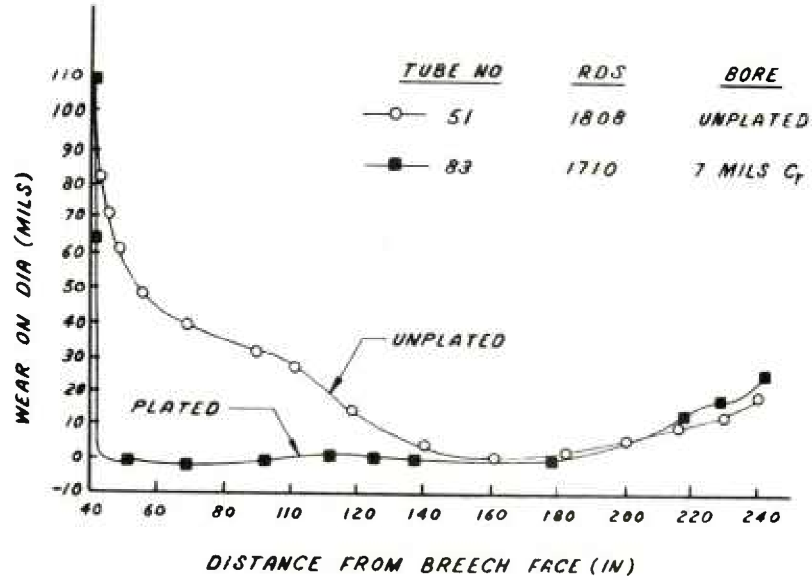

FIGURE 7. EROSION PROFILE OF PLATED AND UNPLATED 155 MM BARREL AFTER FIRING.

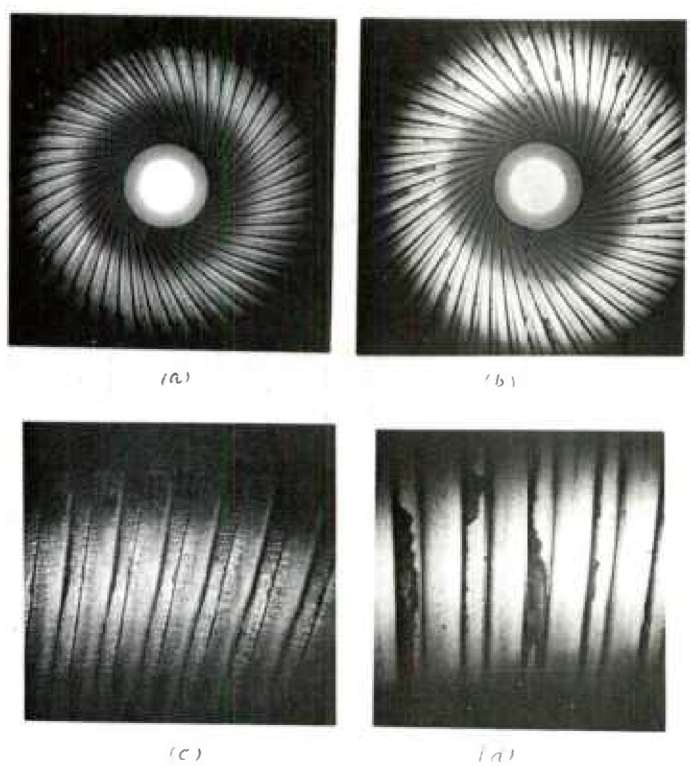

FIGURE 8. A VIEW OF THE CHROME PLATED BORE SURFACE BEFORE AND AFTER FIRING. (A) AS PLATED AT O.R., (B) AFTER 250 RDS AT O.R., (C) AFTER 250 RDS DOWN BORE, (D) CHIPPING ON THE ENGRAVING SIDE 142 IN. FROM REAR FACE OF THE GUN.

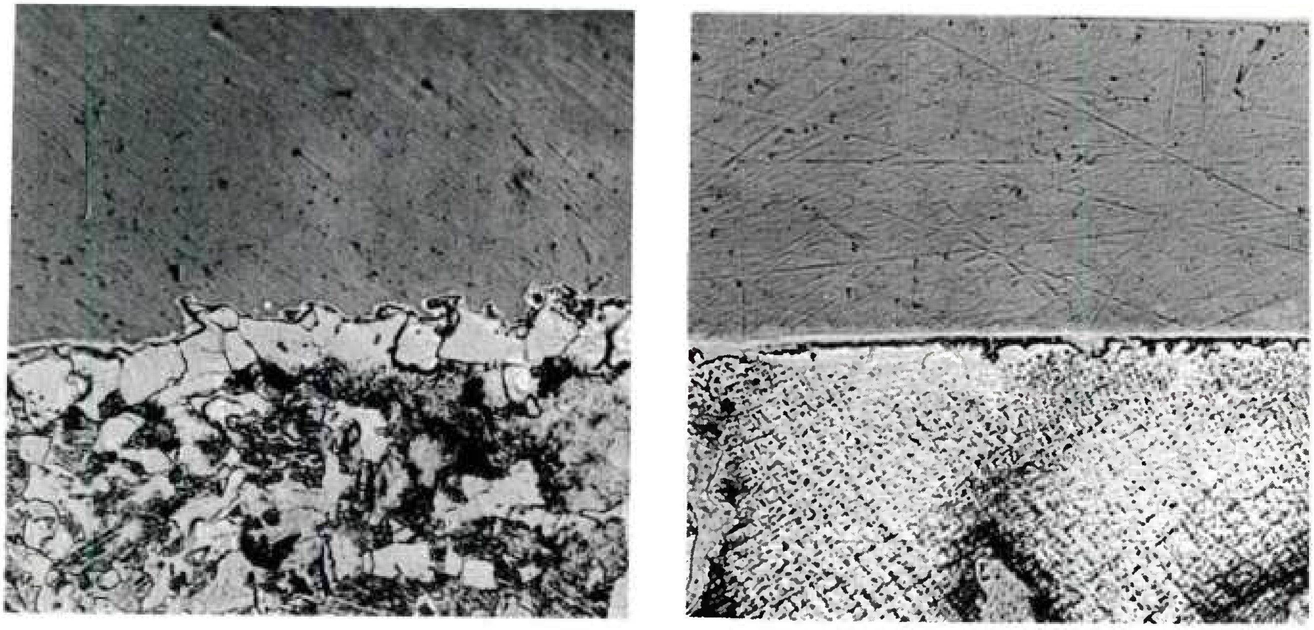

FIGURE 9. (A) Ta/STEEL, (B) Ta/STELLITE 21 INTERFACE AS RECEIVED AFTER Ta PLATING. MAG. 1000X.

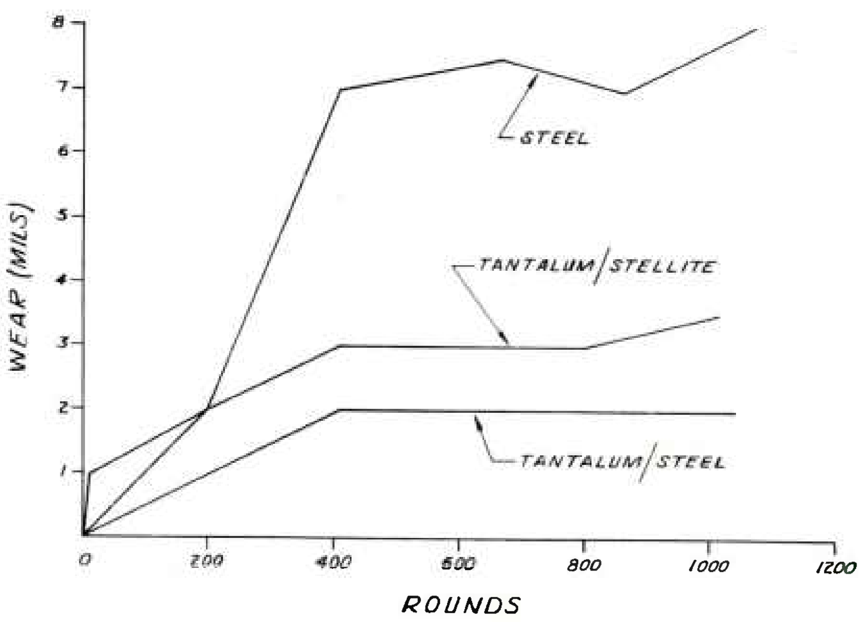

FIGURE 10. WEAR VS. NUMBER OF ROUNDS OF 20 MM BARRELS WITH (A) UNPLATED LINER, (B) Ta PLATED STELLITE 21 AND (C) Ta PLATED GUN STEEL LINER.

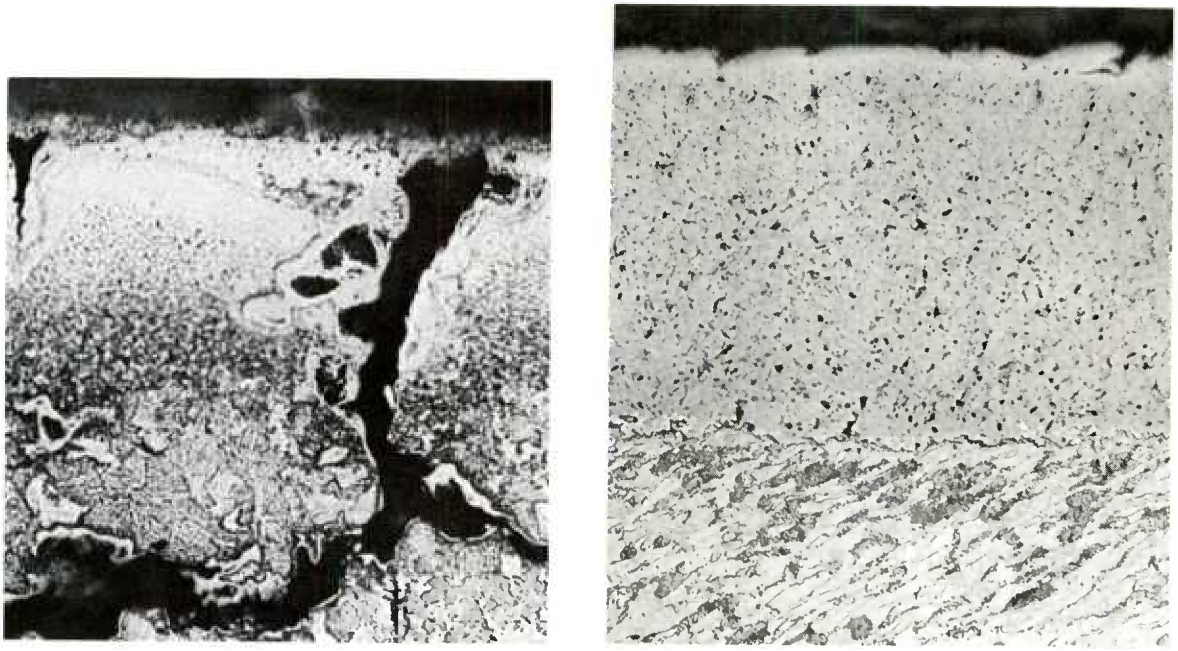

FIGURE 11. (A) Ta COATED STEEL LINER AFTER 1100 RDS. MAG. 500X.
(B) UNPLATED STEEL LINER AFTER 2500 RDS. MAG. 500X.

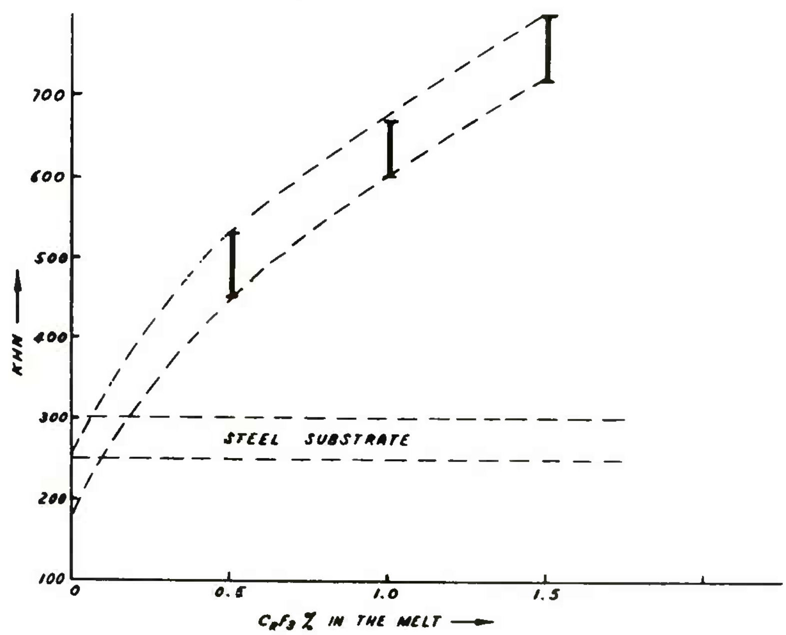

FIGURE 12. EFFECT OF ADDITION OF CrF_3 IN THE FUSED FLOURIDE MELT ON THE ROOM TEMPERATURE OF Ta COATING.

EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH & DEVELOPMENT ATTN: DEP FOR SCI & TECH THE PENTAGON WASHINGTON, D.C. 20315	1
COMMANDER US ARMY MAT DEV & READ. COMD ATTN: DRCDE 5001 EISENHOWER AVE ALEXANDRIA, VA 22333	1
COMMANDER US ARMY ARRADCOM ATTN: DRDAR-TSS DRDAR-LCA (PLASTICS TECH EVAL CEN) DOVER, NJ 07801	 2 1
COMMANDER US ARMY ARRCOM ATTN: DRSAR-LEP-L ROCK ISLAND ARSENAL ROCK ISLAND, IL 61299	1
DIRECTOR US ARMY BALLISTIC RESEARCH LABORATORY ATTN: DRDAR-TSB-S (STINFO) ABERDEEN PROVING GROUND, MD 21005	1
COMMANDER US ARMY ELECTRONICS COMD ATTN: TECH LIB FT MONMOUTH, NJ 07703	1
COMMANDER US ARMY MOBILITY EQUIP R&D COMD ATTN: TECH LIB FT BELVOIR, VA 22060	1

	NO. OF COPIES
COMMANDER US ARMY TANK-AUTMV R&D COMD ATTN: TECH LIB - DRDTA-UL MAT LAB - DRDTA-RK WARREN, MICHIGAN 48090	 1 1
COMMANDER US MILITARY ACADEMY ATTN: CHMN, MECH ENGR DEPT WEST POINT, NY 10996	1
COMMANDER REDSTONE ARSENAL ATTN: DRSMI-RB DRSMI-RRS DRSMI-RSM ALABAMA 35809	 2 1 1
COMMANDER ROCK ISLAND ARSENAL ATTN: SARRI-ENM (MAT SCI DIV) ROCK ISLAND, IL 61202	1
COMMANDER HQ, US ARMY AVN SCH ATTN: OFC OF THE LIBRARIAN FT RUCKER, ALABAMA 36362	1
COMMANDER US ARMY FGN SCIENCE & TECH CEN ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1
COMMANDER US ARMY MATERIALS & MECHANICS RESEARCH CENTER ATTN: TECH LIB -DRXMR-PL WATERTOWN, MASS 02172	2

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.

EXTERNAL DISTRIBUTION LIST (CONT)

	NO. OF COPIES
COMMANDER US ARMY RESEARCH OFFICE P.O. BOX 1211 RESEARCH TRIANGLE PARK, NC 27709	1
COMMANDER US ARMY HARRY DIAMOND LAB ATTN: TECH LIB 2800 POWDER MILL ROAD ADELPHIA, MD 20783	1
DIRECTOR US ARMY INDUSTRIAL BASE ENG ACT ATTN: DRXPE-MT ROCK ISLAND, IL 61201	1
CHIEF, MATERIALS BRANCH US ARMY R&S GROUP, EUR BOX 65, FPO N.Y. 09510	1
COMMANDER NAVAL SURFACE WEAPONS CEN ATTN: CHIEF, MAT SCIENCE DIV DAHLGREN, VA 22448	1
DIRECTOR US NAVAL RESEARCH LAB ATTN: DIR, MECH DIV CODE 26-27 (DOC LIB) WASHINGTON, D.C. 20375	1 1
NASA SCIENTIFIC & TECH INFO FAC P.O. BOX 8757, ATTN: ACQ BR BALTIMORE/WASHINGTON INTL AIRPORT MARYLAND 21240	1

	NO. OF COPIES
COMMANDER DEFENSE DOCU CEN ATTN: DDC-TCA CAMERON STATION ALEXANDRIA, VA 22314	12
METALS & CERAMICS INFO CEN BATTELLE COLUMBUS LAB 505 KING AVE COLUMBUS, OHIO 43201	1
MPDC 13919 W. BAY SHORE DR. TRAVERSE CITY, MI 49684	1
MATERIEL SYSTEMS ANALYSIS ACTV ATTN: DRXSY-MP ABERDEEN PROVING GROUND MARYLAND 21005	1

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.

WATERVLIET ARSENAL INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
COMMANDER	1
DIRECTOR, BENET WEAPONS LABORATORY	1
CHIEF, DEVELOPMENT ENGINEERING BRANCH	1
ATTN: DRDAR-LCB-DA	1
-DM	1
-DP	1
-DR	1
-DS	1
-DC	1
CHIEF, ENGINEERING SUPPORT BRANCH	1
CHIEF, RESEARCH BRANCH	2
ATTN: DRDAR-LCB-RA	1
-RC	1
-RM	1
-RP	1
TECHNICAL LIBRARY	5
TECHNICAL PUBLICATIONS & EDITING UNIT	2
DIRECTOR, OPERATIONS DIRECTORATE	1
DIRECTOR, PROCUREMENT DIRECTORATE	1
DIRECTOR, PRODUCT ASSURANCE DIRECTORATE	1

NOTE: PLEASE NOTIFY DIRECTOR, BENET WEAPONS LABORATORY, ATTN: DRDAR-LCB-TL, OF ANY REQUIRED CHANGES.