

AD

MEMORANDUM REPORT ARCCB-MR-00006

**CRITICAL COMMENTS ON REPORT TITLED  
"GRAY LAYERS AND THE EROSION OF CHROMIUM  
PLATED GUN BORE SURFACES" BY COTE AND RICKARD**

**J. H. UNDERWOOD**

APRIL 2000

	<p><b>US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER CLOSE COMBAT ARMAMENTS CENTER BENÉT LABORATORIES WATERVLIET, N.Y. 12189-4050</b></p>	
---	--	---

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

20000523 030

DTIC QUALITY INSPECTED 1

## **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 endorsement or approval.

## **DESTRUCTION NOTICE**

For classified documents, follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19, or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

For unclassified, unlimited documents, destroy when the report is no longer needed. Do not return it to the originator.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE April 2000	3. REPORT TYPE AND DATES COVERED Final		
4. TITLE AND SUBTITLE CRITICAL COMMENTS ON REPORT TITLED "GRAY LAYERS AND THE EROSION OF CHROMIUM PLATED GUN BORE SURFACES" BY COTE AND RICKARD			5. FUNDING NUMBERS PRON No. TU9B9F101ABJ	
6. AUTHOR(S) J.H. Underwood				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army ARDEC Benet Laboratories, AMSTA-AR-CCB-O Watervliet, NY 12189-4050			8. PERFORMING ORGANIZATION REPORT NUMBER  ARCCB-MR-00006	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army ARDEC Close Combat Armaments Center Picatinny Arsenal, NJ 07806-5000			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) In June 1999, Dr. Cote supplied a prepublication copy of his and Mr. Rickard's report, "Gray Layers and the Erosion of Chromium Plated Gun Bore Surfaces," and requested this author's comments. These comments are offered here.				
14. SUBJECT TERMS Erosion, Thermal Damage, Cannons, Chromium Plate			15. NUMBER OF PAGES 4	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

## TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION.....	1
CAUSE OR CONSEQUENCE.....	1
COMPARISON OF HYDROGEN CRACKS AND GRAY LAYERS.....	1
Morphology of Cracks and Gray Layers .....	1
Time and Temperature Requirements .....	2
REFERENCES.....	3

## INTRODUCTION

In June 1999, Dr. Cote supplied a prepublication copy of his and Mr. Rickard's report, "*Gray Layers and the Erosion of Chromium Plated Gun Bore Surfaces*," (ref 1) and requested this author's comments. These comments are offered here.

Erosion of gun bore surfaces is clearly one of the most critical topics facing ARDEC, so the authors should be complimented for undertaking this work. They apply both proven and novel metallography methods to samples from guns that were fired with recent, high-temperature rounds. Thus, their results deserve attention.

## CAUSE OR CONSEQUENCE

The problem this author has with their report is with the main conclusion of the work, which is well stated in the authors' words from their Discussion section:

*"...the present observations of the initiation and gradual progression of oxygen and sulfur attack into the steel do not support the suggestion that hydrogen cracking of the steel, after firing, initiates failure of the chromium."*

Cote and Rickard conclude that oxygen and sulfur attack of the steel is the cause of chromium loss and erosion in guns, and that hydrogen cracking is not involved. This author disagrees with this conclusion, and suggests that hydrogen cracking is the initial and critical cause of steel damage and subsequent chromium loss and erosion, whereas oxygen and sulfur attack occurs **after** hydrogen cracking as a consequence of that cracking. Simply stated, hydrogen cracking is the initial cause of chromium loss, and gray layer formation is a consequence of hydrogen cracking. Thus, gray layers could have at most a secondary effect on chromium loss and erosion in cannon tubes. A comparison of certain aspects of hydrogen cracking and gray layer formation—based on Figures 5 and 7a of the Cote and Rickard report and on prior ARDEC reports—is given below, to support the contention that hydrogen cracks are a cause and gray layers are a consequence.

## COMPARISON OF HYDROGEN CRACKS AND GRAY LAYERS

### Morphology of Cracks and Gray Layers

It is clear from Figures 5 and 7a (and supported by other Cote and Rickard photomicrographs) that gray layers are observed as, "*outlining many of the larger crack-like features*," again using the authors' words. The obvious explanation for this configuration of a crack outlined by a gray layer is that the crack formed after the required number of firings and **then** opened in subsequent firings to admit propellant gases that formed the gray layer. So the cracks cause the initial damage in the steel beneath the chromium, and the gray layers are a consequence of the cracks. Further, based on recent work at Benet (refs 2,3) and a long progression of results from the literature, it is clear

that the cracks in Figures 5 and 7a have the characteristic features of hydrogen cracks as observed in cannons and other components.

### Time and Temperature Requirements

Vigilante and coworkers (ref 3) and others in the literature have shown that hydrogen cracks can grow very quickly in gun steel at room temperature. Also, there is clear evidence (ref 2) that cannon firing provides the sustained tensile stress and hydrogen environment required for hydrogen cracking. Thus, it is quite plausible that the cracks shown in Figures 5 and 7a are hydrogen cracks.

In contrast, there seems to be considerable question that the cracks shown in Figures 5 and 7a could have been formed by "*the gradual progression of oxygen and sulfur attack into the steel.*" It is doubtful that there could have been enough time at temperature. It is known that the high temperatures required for sulfur attack have only a few milliseconds duration during a cannon firing cycle, whereas an example of sulfidation cracking from the literature (ref 4) led to failure only after 8500 hours at 1700°F. So the growth of a long slender gray layer along a line to somehow cause the crack-like appearance in Figures 5 and 7a does not seem very plausible. The very shape of the "*crack-like features*" in Figures 5 and 7a support this. The length extending into the steel is clearly very much greater than the width, and this is consistent with a hydrogen crack growing in response to a **sustained** tensile stress, followed by much slower growth of gray layers in response to a **brief** high-temperature exposure during subsequent firing cycles.

## REFERENCES

1. Cote, Paul J., and Rickard, Christopher, "Gray Layers and the Erosion of Chromium Plated Gun Bore Surfaces," ARDEC Technical Report ARCCB-TR-99016, Benet Laboratories, Watervliet, NY, September 1999.
2. Underwood, J.H., Parker, A.P., Cote, P.J., and Sopok, S., "Compressive Thermal Yielding Leading to Hydrogen Cracking in a Fired Cannon," *Journal of Pressure Vessel Technology*, 1999.
3. Vigilante, G.N., Underwood, J.H., and Crayon, D., "Use of the Instrumented Bolt and Constant Displacement Bolt-Loaded Specimen to Measure In-Situ Hydrogen Crack Growth in High Strength Steels," *Fatigue and Fracture Mechanics: 30th Volume, ASTM STP 1360*, American Society for Testing and Materials, 1999.
4. *Metals Handbook, Ninth Edition, Vol. 12, Fractography*, ASM International, Metals Park, OH, 1987, p. 388.

---

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	<u>NO. OF COPIES</u>
TECHNICAL LIBRARY ATTN: AMSTA-AR-CCB-O	5
TECHNICAL PUBLICATIONS & EDITING SECTION ATTN: AMSTA-AR-CCB-O	3
OPERATIONS DIRECTORATE ATTN: SIOVV-ODP-P	1
DIRECTOR, PROCUREMENT & CONTRACTING DIRECTORATE ATTN: SIOVV-PP	1
DIRECTOR, PRODUCT ASSURANCE & TEST DIRECTORATE ATTN: SIOVV-QA	1

NOTE: PLEASE NOTIFY DIRECTOR, BENÉT LABORATORIES, ATTN: AMSTA-AR-CCB-O OF ADDRESS CHANGES.

---

---

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	<u>NO. OF COPIES</u>		<u>NO. OF COPIES</u>
DEFENSE TECHNICAL INFO CENTER ATTN: DTIC-OCA (ACQUISITIONS) 8725 JOHN J. KINGMAN ROAD STE 0944 FT. BELVOIR, VA 22060-6218	2	COMMANDER ROCK ISLAND ARSENAL ATTN: SIORI-SEM-L ROCK ISLAND, IL 61299-5001	1
COMMANDER U.S. ARMY ARDEC ATTN: AMSTA-AR-WEE, BLDG. 3022 AMSTA-AR-AET-O, BLDG. 183 AMSTA-AR-FSA, BLDG. 61 AMSTA-AR-FSX AMSTA-AR-FSA-M, BLDG. 61 SO AMSTA-AR-WEL-TL, BLDG. 59 PICATINNY ARSENAL, NJ 07806-5000	1 1 1 1 1 2	COMMANDER U.S. ARMY TANK-AUTMV R&D COMMAND ATTN: AMSTA-DDL (TECH LIBRARY) WARREN, MI 48397-5000	1
DIRECTOR U.S. ARMY RESEARCH LABORATORY ATTN: AMSRL-DD-T, BLDG. 305 ABERDEEN PROVING GROUND, MD 21005-5066	1	COMMANDER U.S. MILITARY ACADEMY ATTN: DEPT OF CIVIL & MECH ENGR WEST POINT, NY 10966-1792	1
DIRECTOR U.S. ARMY RESEARCH LABORATORY ATTN: AMSRL-WM-MB (DR. B. BURNS) ABERDEEN PROVING GROUND, MD 21005-5066	1	U.S. ARMY AVIATION AND MISSILE COM REDSTONE SCIENTIFIC INFO CENTER ATTN: AMSAM-RD-OB-R (DOCUMENTS) REDSTONE ARSENAL, AL 35898-5000	2
COMMANDER U.S. ARMY RESEARCH OFFICE ATTN: TECHNICAL LIBRARIAN P.O. BOX 12211 4300 S. MIAMI BOULEVARD RESEARCH TRIANGLE PARK, NC 27709-2211	1	COMMANDER U.S. ARMY FOREIGN SCI & TECH CENTER ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1

---

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER,  
BENÉT LABORATORIES, CCAC, U.S. ARMY TANK-AUTOMOTIVE AND ARMAMENTS COMMAND,  
AMSTA-AR-CCB-O, WATERVLIET, NY 12189-4050 OF ADDRESS CHANGES.

---