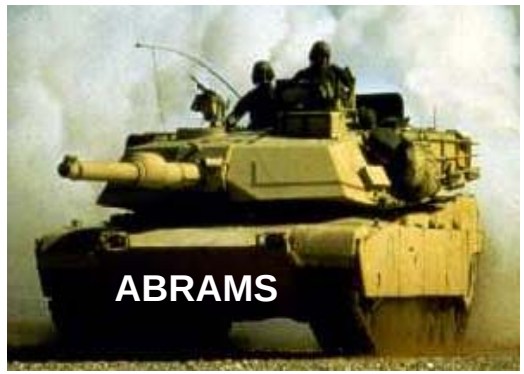
U.S. Army Benet Laboratories

Hard Chrome Alternatives Team
20-21 July, 2004, Utah

ARDEC

Elimination of Chromium Electrodeposition from Large Caliber Launch Systems



Name of Briefer: Krystyna Truszkowska
US Army Benet Laboratories
part of the US Army Armaments Research, Development and Engineering Center

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUL 2004		**00-00-2004 to 00-00-2004**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Elimination of Chromium Electrodeposition from Large Caliber Launch Systems	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Benet Laboratories,Picatinny Arsenal,NJ,07806**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
24th Replacement of Hard Chrome Plating Program Review Meeting, July 20-21, 2004, Park City, UT. Sponsored by SERDP/ESTCP.

14. ABSTRACT

15. SUBJECT TERMS

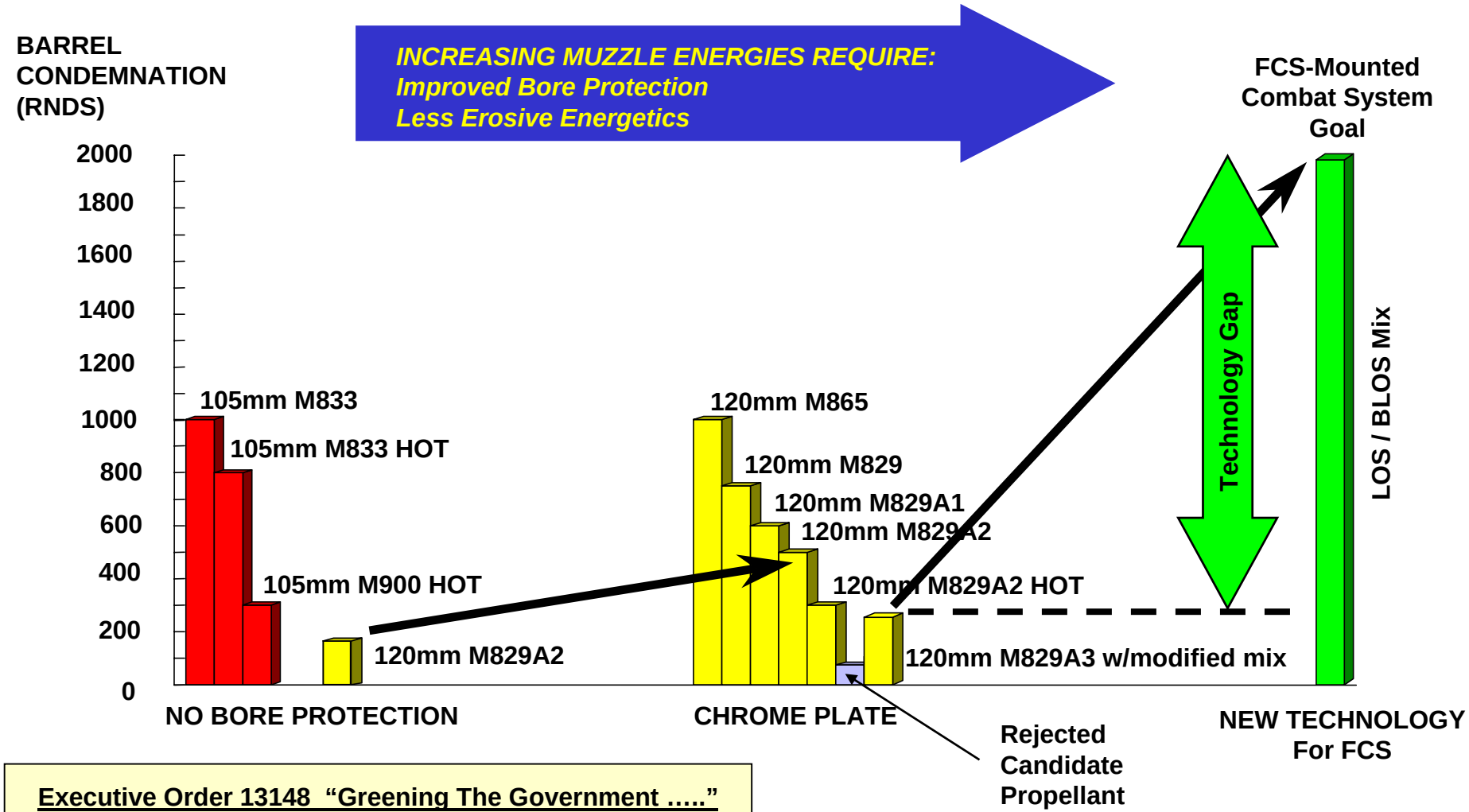
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**20**	

LARGE CALIBER GUN EROSION

Direct Fire

U.S. Army Benet Laboratories

ARDEC



Executive Order 13148 "Greening The Government ….."

Reduction of Toxic Chemical Releases by 40% by 31 Dec 2006

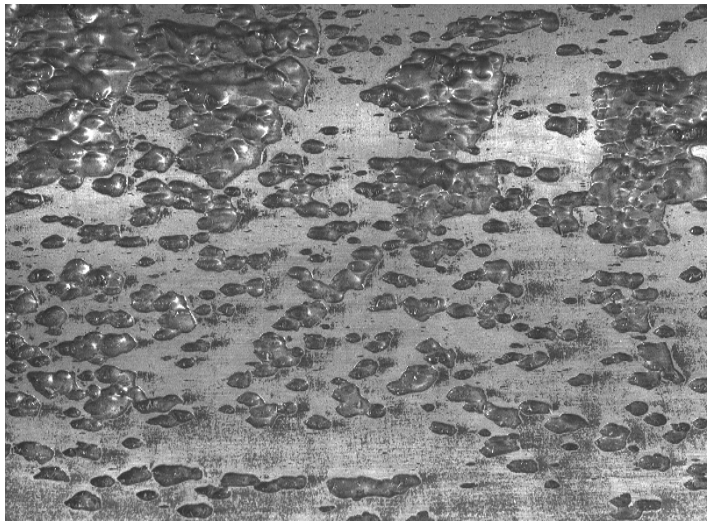
Reduction of Toxic Chemical Usage by 50% by 31 Dec 2006

U.S. Army Benet Laboratories

120mm GUN BARREL DEGRADATION

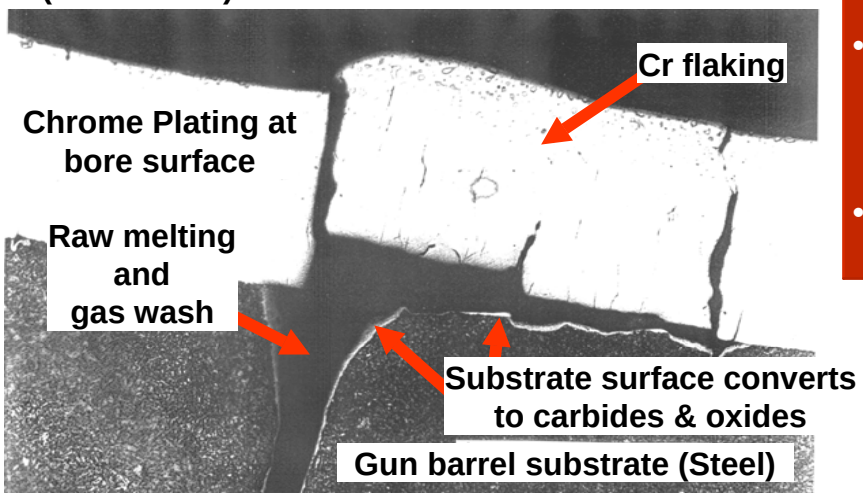
Classic Erosion Defined

ARDEC



Condemned ABRAMS 120mm GUN BARREL

(214 rounds) : **> 5mm erosion**



- HC Chrome is produced in an “as cracked” condition offering path to substrate
- HC Cr contaminants off-gas causing further material volume shrinkage and stress-relief cracking
- Combustion products:
  - Penetrate cracks
  - Alter steel substrate phase
  - Convert substrate surface to carbides & oxides
  - Lowers MP of substrate surface
- Gas wash:
  - Removes lower MP substrate surface
  - Erodes Cr foundation (compromised adherence)
- Departing Cr exposes more substrate to high velocity gas wash and further erosion

U.S. Army Benet Laboratories

120mm GUN BARREL MANUFACTURING PROCESS

ARDEC

Billet → Rotary Forge → Heat Treat → Rough Machining → Autofrettage → Post-Autofrettage Thermal Soak → Finish Machining → Chrome Plate → Inspection → Ship

Rotary Forging

Machining

Chrome Plating

Fielding

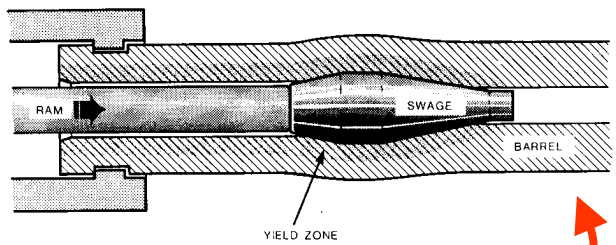
U.S. Army Benet Laboratories

LARGE CALIBER GUN COATING REQUIREMENTS

Material & Deposition Process Requirements

ARDEC

MATERIAL CHARACTERISTIC	CRITERIA
Melting Point	*Cr (1875 C) or better*
Elastic Modulus	*Compatible with substrate* ***(facilitates low surface crack densities)***
YS at Elevated Temps	*High*
Fracture Toughness	*High*
Hot Hardness	*High (appropriate)*
Chemical Resistance	*High*
Coefficient of Thermal Exp.	*Compatible with substrate*
Thermal Conductivity	*Low*
Reaction w/ Rotating Band	*Inert*
Phase Transformations	*None*



PROCESS CHARACTERISTIC	CRITERIA
Deposition Temperature	*Less than 357C* ***(post autofrettage thermal soak limit)***
Deposit Rate	*1 mil of coating material per hour*
Surface Finish	*Equal or better than 32 RMS at deposition*
Deposition Length	*58 Calibers or greater*
Hazardous Impacts	*None or limited*

U.S. Army Benet Laboratories

COATING DEPOSITION PROCESS SELECTION

for Large Caliber Guns

ARDEC

FUNCTIONAL REQUIREMENTS	PROCESS								
	Molten Salt	Plasma Spray	Chem. Vapor Dep.	Ion Implant.	Ion Plate	Explosive Bonding	Metal liding	Aqueous Electro-Dep	Cyl Magnetron Sputtering
Autofrettage Stresses Protected				✓	✓			✓	✓
No Post-process Surface Finish Req	✓			✓		✓	✓	✓	✓
Acceptable Deposition Rate	✓	✓	✓			✓		✓	✓
Proper Process Aspect Ratio			✓					✓	✓
Accept Dim. and Densities over 50 cal								✓	✓
Acceptable Adhesion	✓					✓		✓	✓
Dry Process		✓	✓	✓	✓	✓	✓		✓
Eliminate Hazardous Materials				✓	✓	✓			✓
Eliminate Air / Water Contamination				✓	✓	✓			✓

•**TECHNICAL PANEL EXPERTS (1997)**

TECHNICAL APPROACH

Technology Maturation Methodology

U.S. Army Benet Laboratories

ARDEC

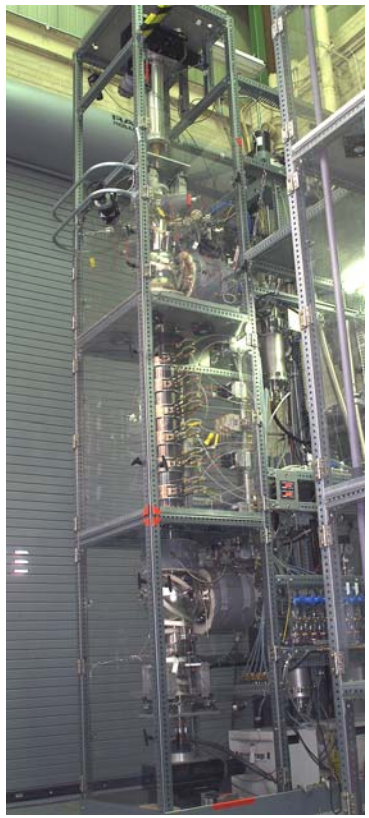
DOE
PLANAR

PROCESS DEV PLATFORM

PRE - PRODUCTION PLATFORM

TEST ASSET FIRING

Coupons &
12” Sections



40” Sections

Full-Length Gun Barrels

BENET SIGNIFICANT ACCOMPLISHMENTS

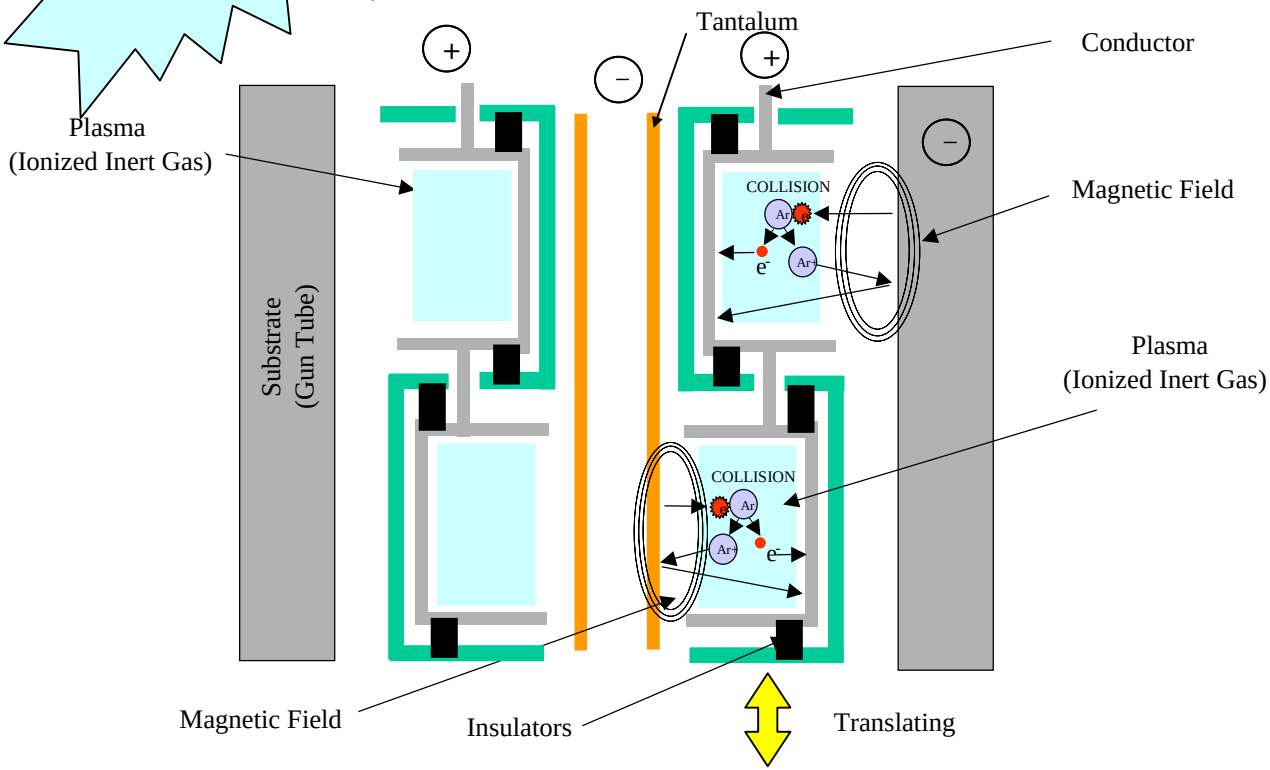
Lg Cal Plasma Cleaning Device (PCD)

ATOMICALLY CLEAN SURFACES

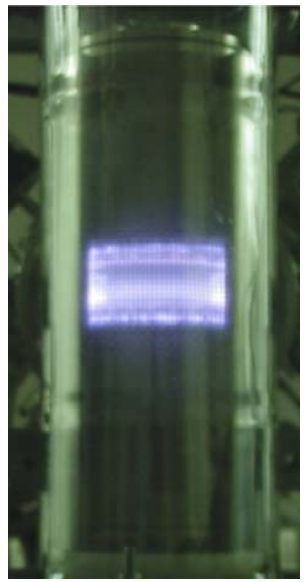
U.S. A… …ories

ARDEC

ARMY PATENT PENDING
Disclosure No. 2002-020



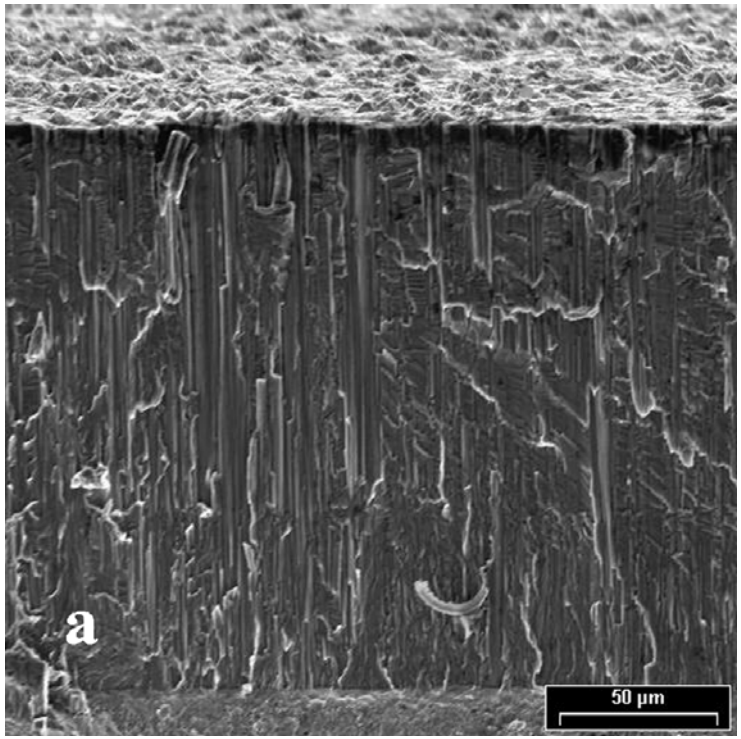
Lg Cal PCD

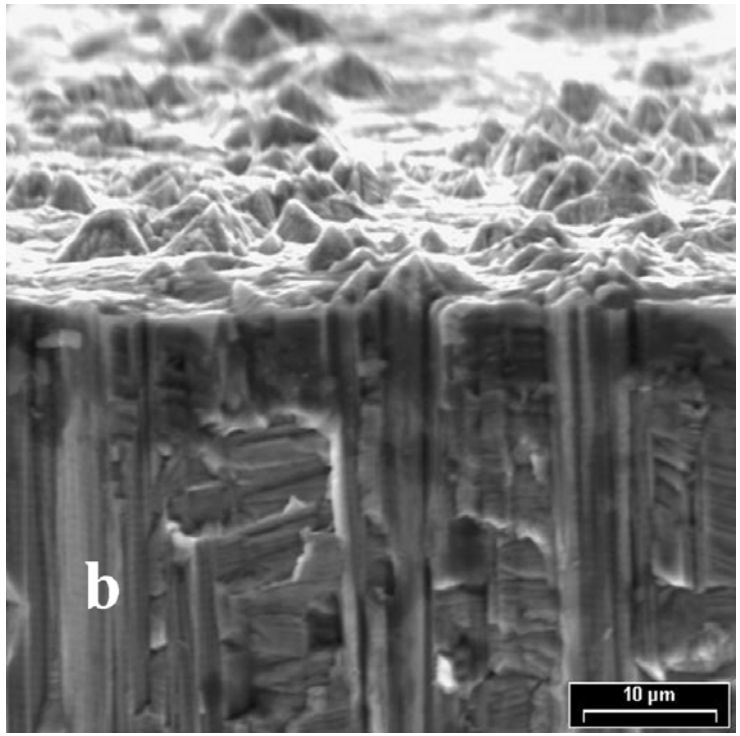


Substrate Cleaning w/PCD

An Army <u>patent pending</u> manufacturing technology to provide "atomically clean" surfaces for CMS deposition onto full length gun barrels

CMS Cr Coating Morphology





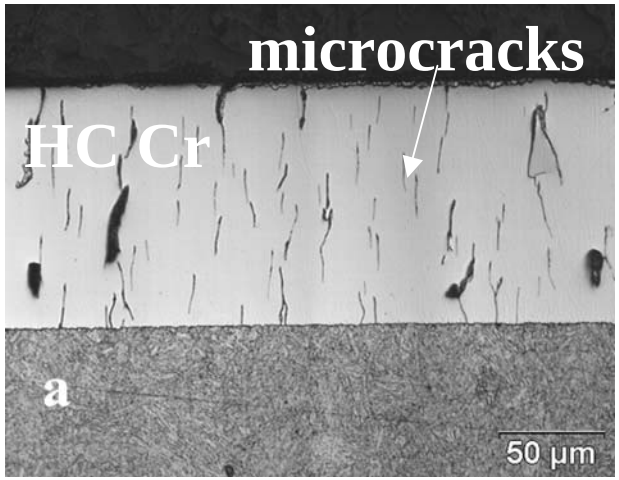
- SEM images of tensile fractured chromium specimens:
  a: dense fibrous grain structure (zone T per Thornton)
  b: small amount of columnar growths
- XRD residual stress study: compressive stress of ~ 30 Ksi

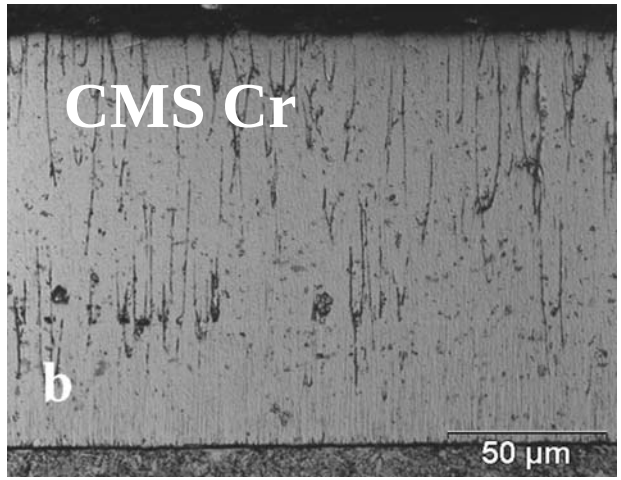
U.S. Army Benet Laboratories

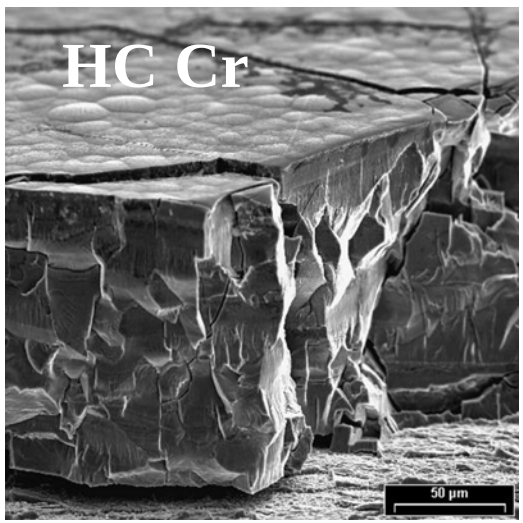
Cr Coating Comparison

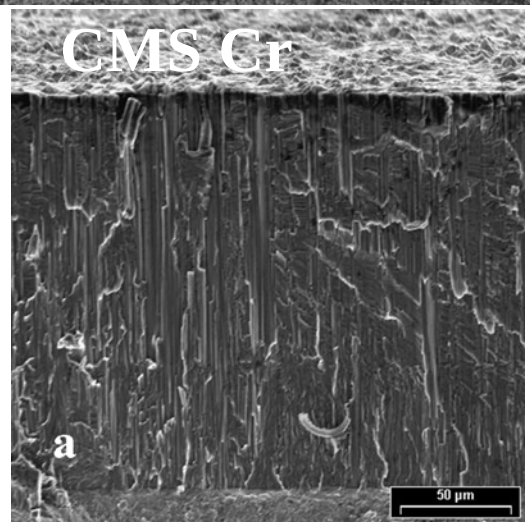
Electropladed vs sputtered

ARDEC







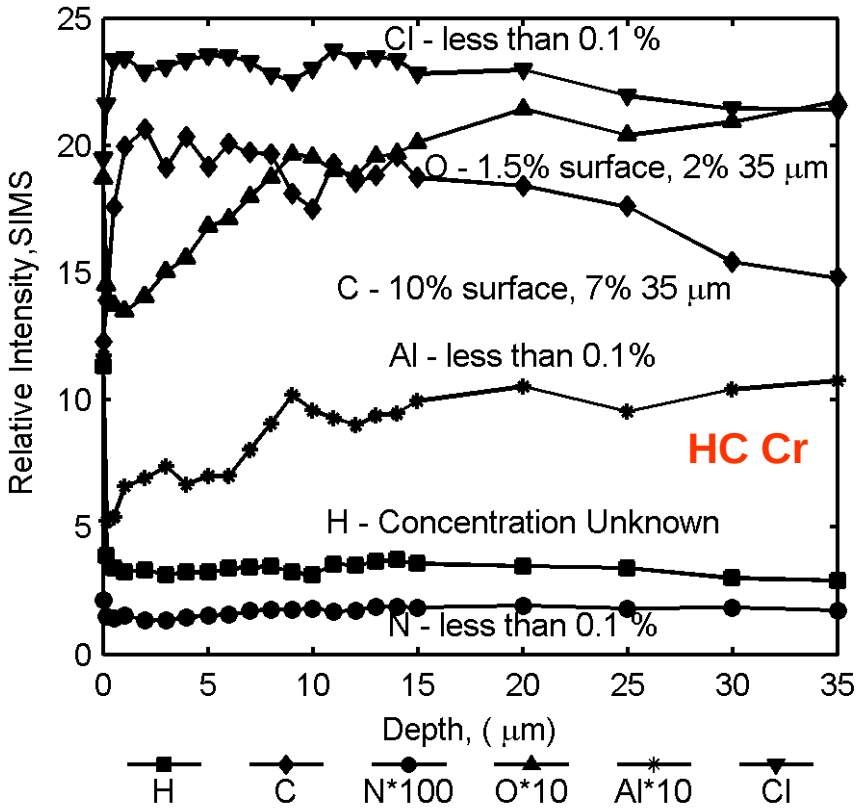


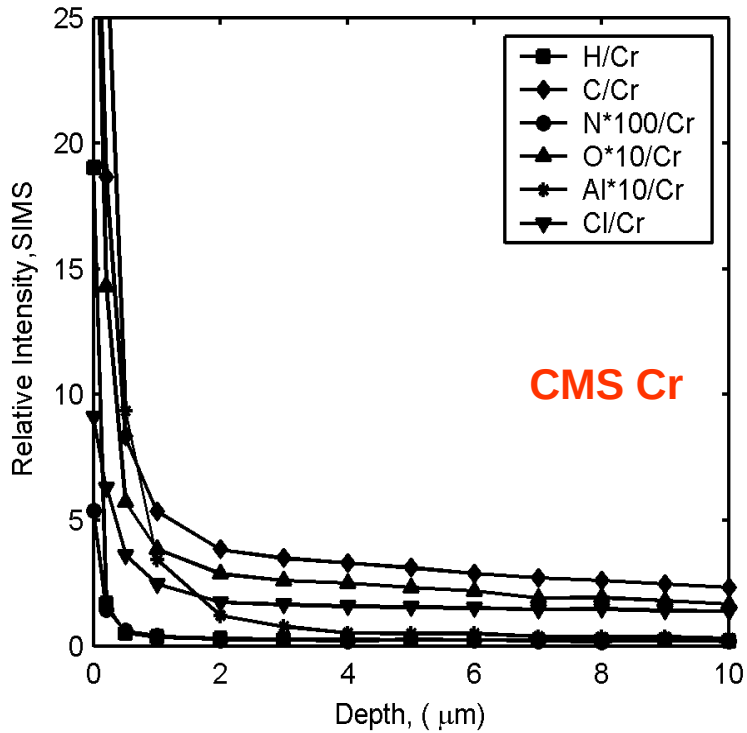
Microhardness: HC Cr 800-1000 HK
CMS Cr 220 - 400 HK

Cr Coating Composition

U.S. Army Benet Laboratories

ARDEC





SIMS peak intensity vs profile depth

Bulk impurity concentration:

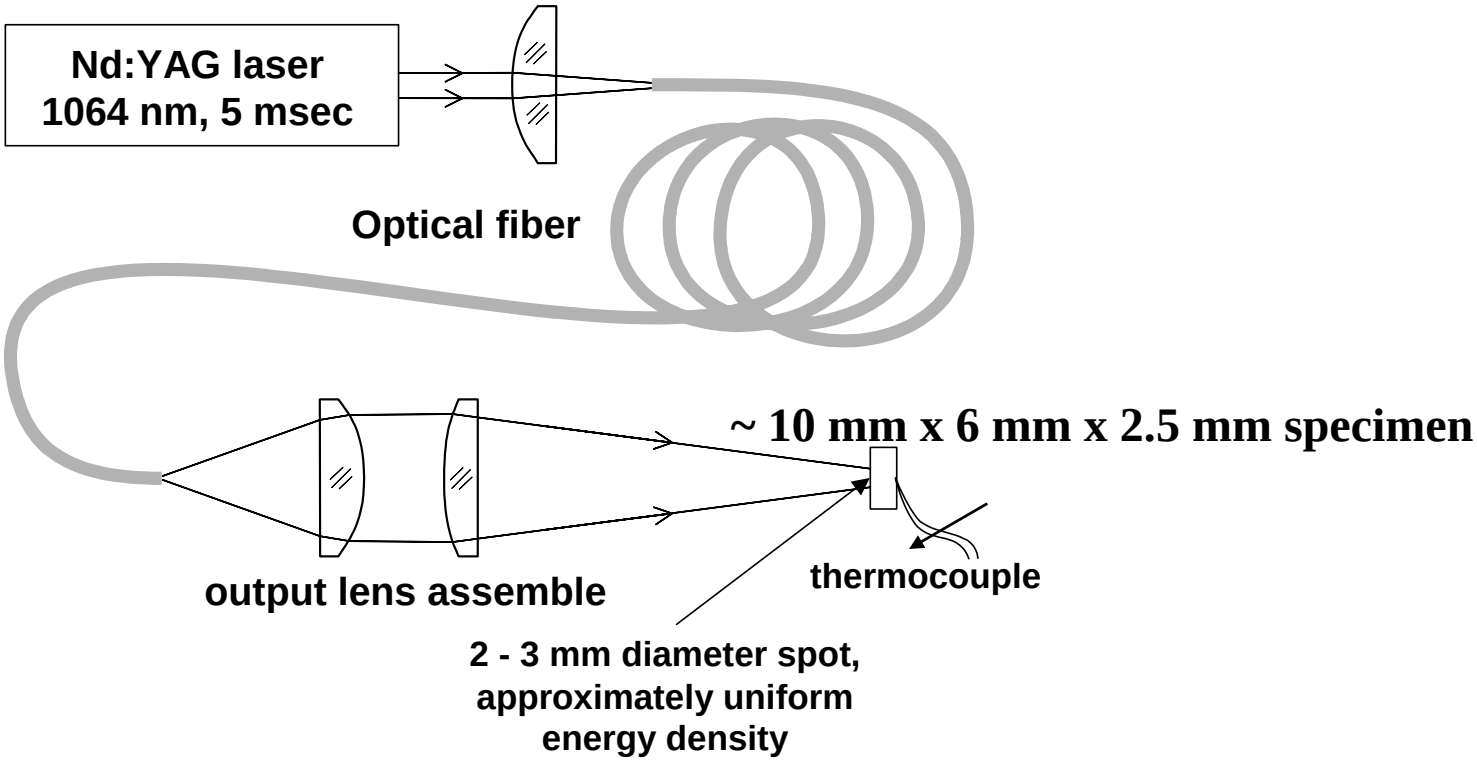
- CMS Cr: all non-Cr elements < 0.1at %
- HC Cr: carbon concentration ~ 10 at %, oxygen concentration ~ 2 at %

Coating Evaluation Process

Adhesion and Erosion Rate

Laser Pulse Heating (LPH) method

Thermal shock resistance



P. Cote et al, Surf. Coat. Technol.163-164, 2003

Coating Evaluation Process Cont.

Adhesion and Erosion Rate

U.S. Army Benet Laboratories

ARDEC

NOVEL SPIN-OFF TECHNOLOGY

Abrams M1A2 Main Battle Tank

Vented Erosion Simulator (VES): *For Interim Coatings Validation*

- **Flame T & chemistry similar to M829A2/M829A3**
- **Accepts Lg Cal coated coupons**
- **Extensively modeled**
- **Does not exceed critical T observed in current gun barrel erosion process**
- **Used to screen, evaluate, optimize, and validate Lg Cal gun bore coatings**

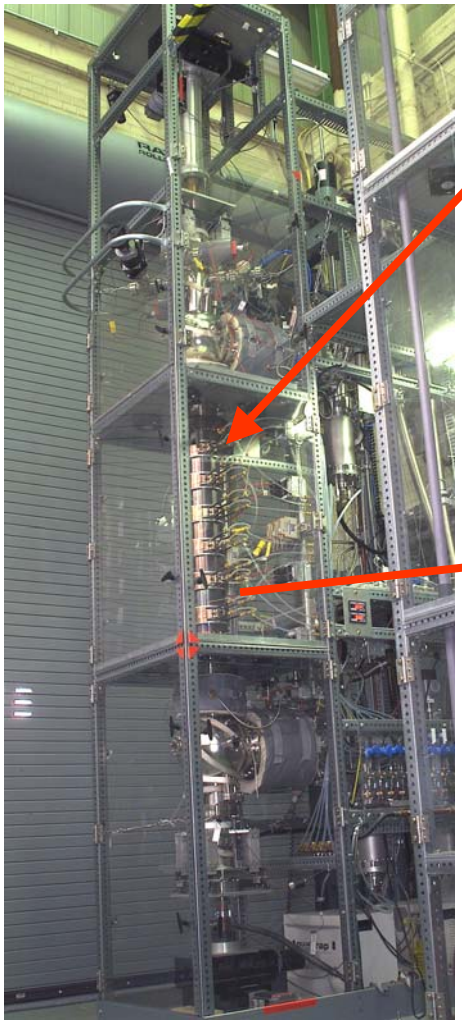
Benet's VES evaluates coatings in a simulated Lg Cal Gun Firing Environment

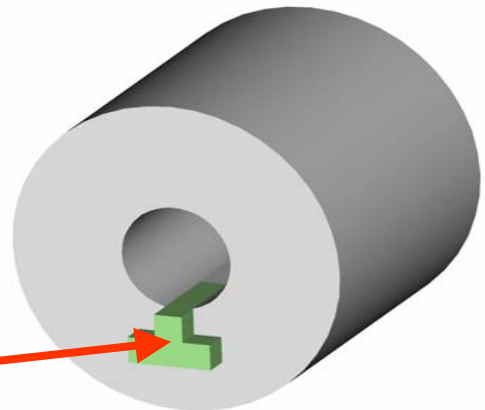
INTERIM COATINGS VALIDATION

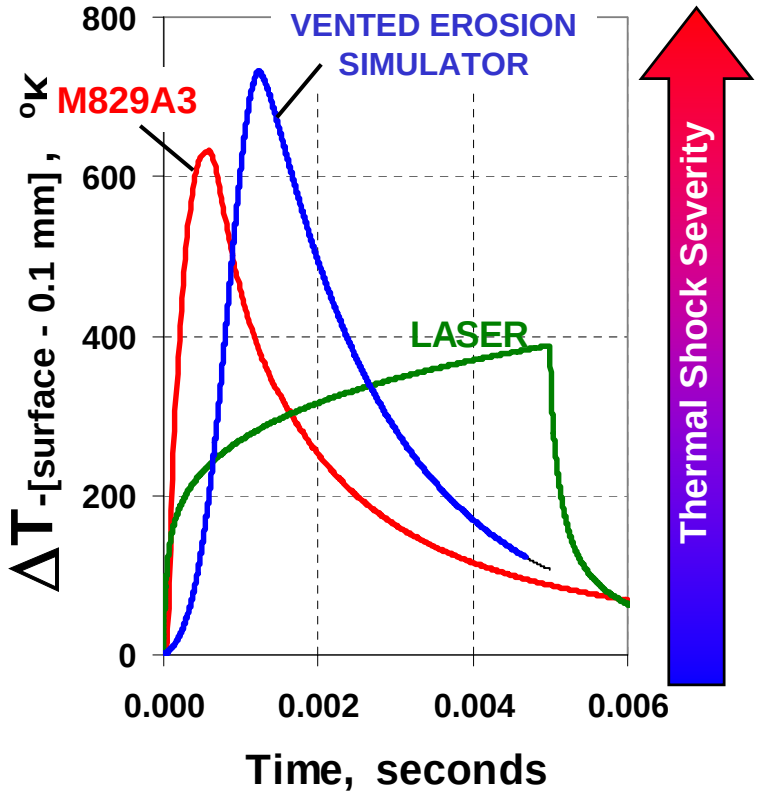
Vented Erosion Simulator (VES) Testing

U.S. Army Benet Laboratories

ARDEC







- Flame T & chemistry similar to M829A2/M829A3
- Accepts Large Caliber coated coupons *(eliminates process scaling)*
- Ballistically modeled & validated
- Substrate transformed to same depth as Lg Cal Gun
- Maintains critical T observed in current gun barrel erosion process

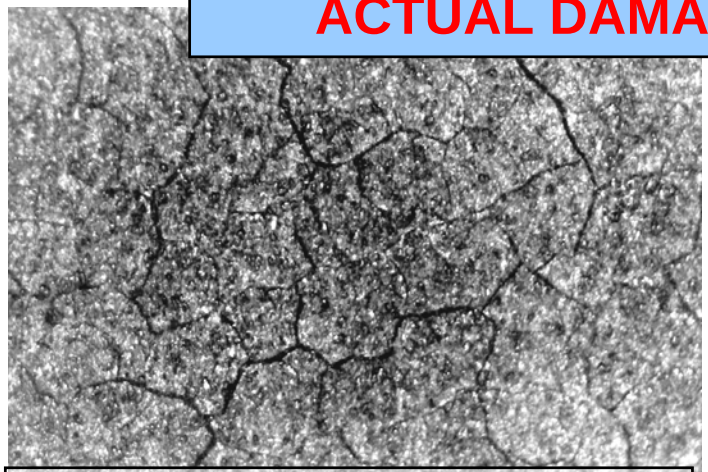
VENTED EROSION SIMULATOR (VES)

an excellent simulation of Lg Cal gun firing

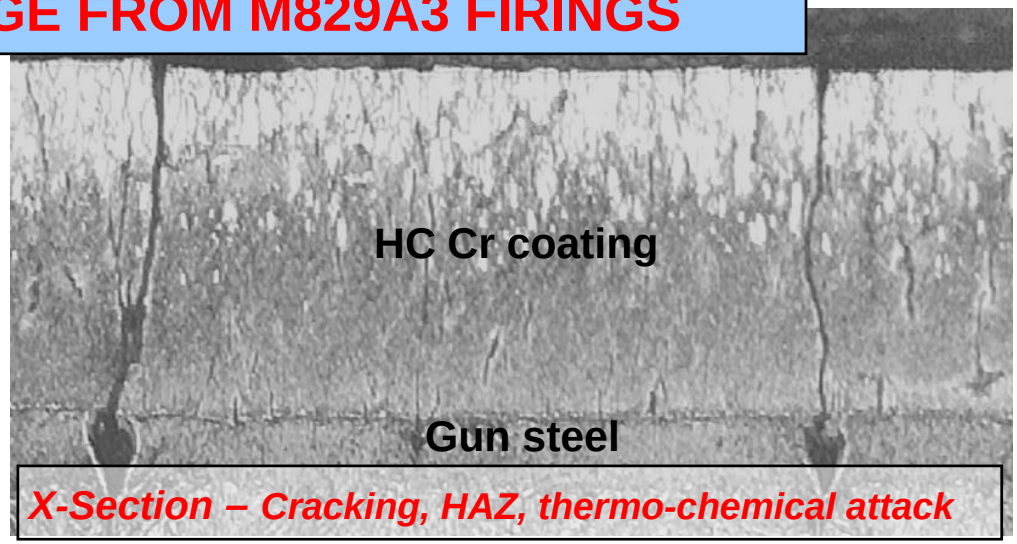
U.S. Army Benet Laboratories

ARDEC

ACTUAL DAMAGE FROM M829A3 FIRINGS

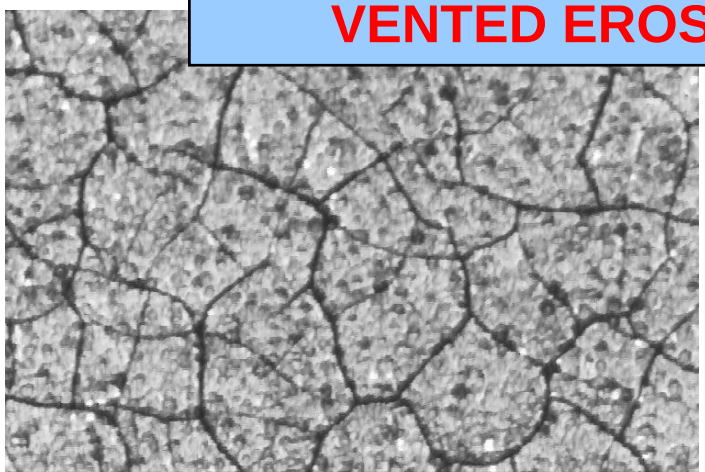


Top View – *Thermal shock cracking*

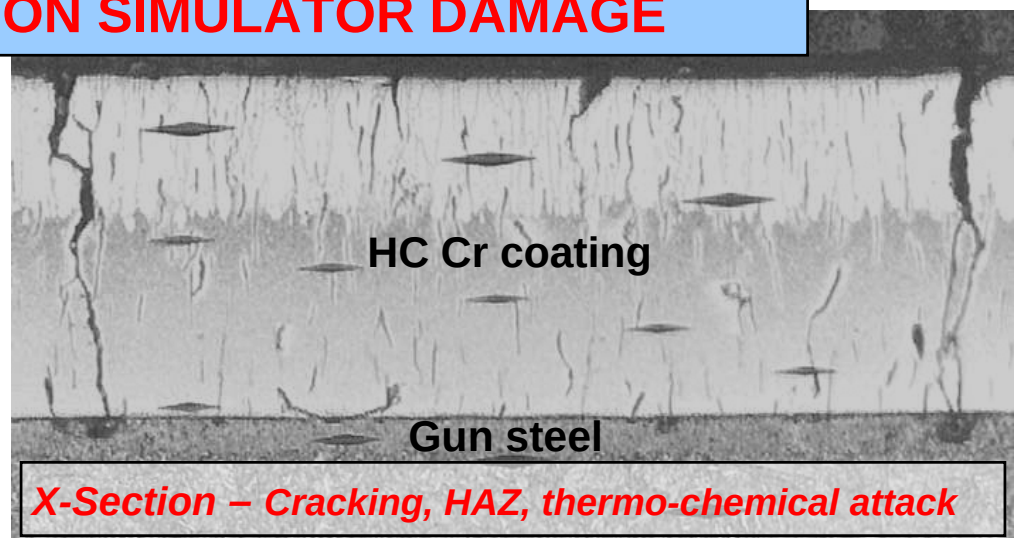


X-Section – Cracking, HAZ, thermo-chemical attack

VENTED EROSION SIMULATOR DAMAGE



Top View – *Thermal shock cracking*



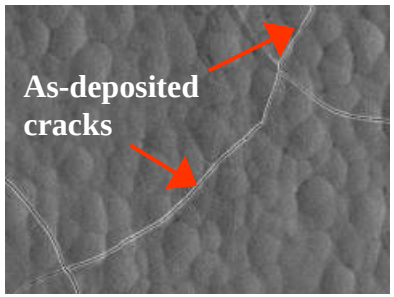
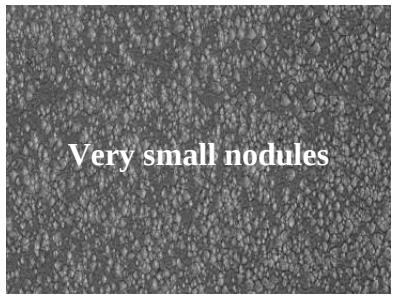
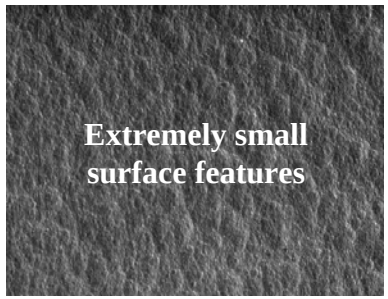
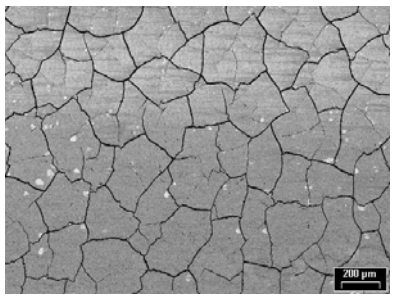
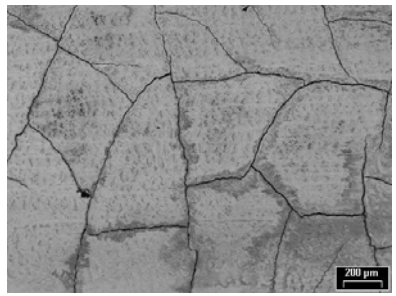
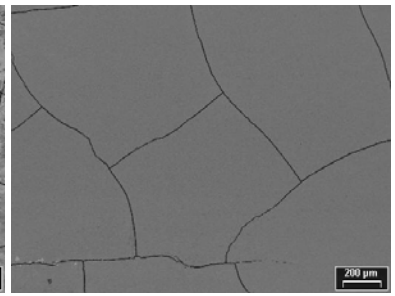
X-Section – Cracking, HAZ, thermo-chemical attack

U.S. Army Benet Laboratories

COATING CRACK DENSITY

Substrate Exposure – Erosion Rate

ARDEC

	HC Cr	Sputtered Cr	Sputtered Ta
As-Deposited Surface Appearance			
Post-firing Crack Island Size (aka Crack Density)			

2mm

120mm Tank Gun Surfaces

Summary of
TECHNICAL METRICS
Advanced Coatings for Large Caliber Guns

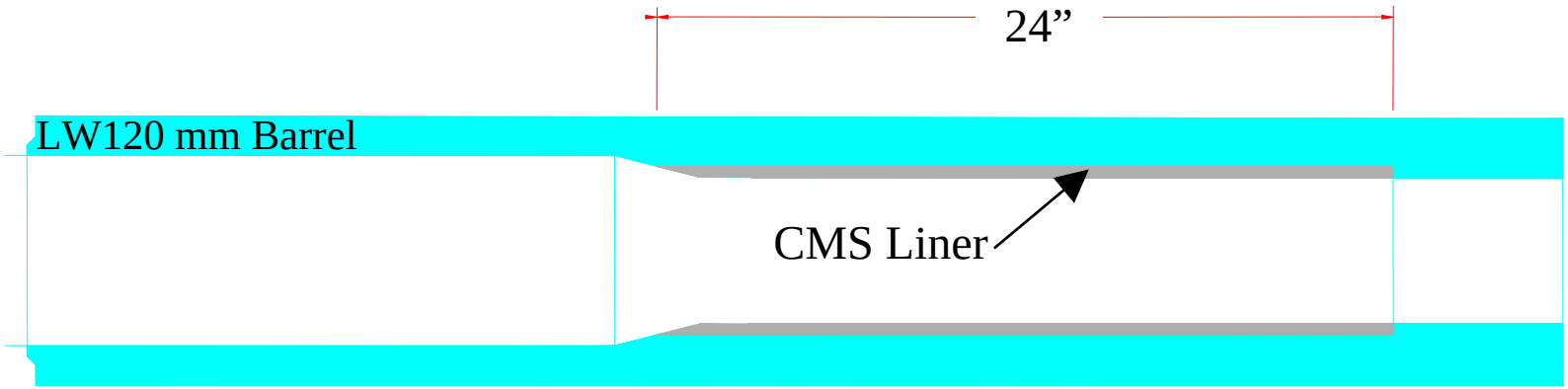
CHARACTERISTIC	Current state of HC CHROME PLATING	Desired end state for SPUTTERING	VERIFICATION TECHNIQUE	CURRENT STATUS
Coating Morphology	Zone 2	Zone 2	Microscopy	yes
Coating Phase	Single	100% Alpha (Ta)	Microscopy	yes
		bcc (Cr)	Microscopy	yes
Hardness	900 -1100 Knoop	200 - 300 Knoop	Microhardness (Ta)	yes
			Microhardness (Cr)	yes
Thermal Shock Resistance	Poor	Excellent	Pulsed Laser	yes
			Vented Erosion Sim	yes
Adhesion / Cohesion	Excellent	Excellent	Groove Testing	yes
			VES (Ta)	yes
			VES (Cr)	yes
Distribution over Length	.002 - .006 in.	Less than .0005	Microscopy	yes (80”)
Distribution around ID	.002 - .006 in.	Less than .0005	Microscopy	yes
Deposition Rate	.001 inches/hr	.001 inches/hr	Microscopy	no (.00075)
Coating Thickness	.002 - .006 in.	.004 - .006 in.	Microscopy	yes
Surface Finish	63 finish	32 or better	Visual	yes (16)
Onset of Erosion	100 VES shots	better	Visual / Microscopy	yes
Weapon Service Erosion Life	260 Rnds (M829A3)	400 Rnds (M829A3)	Firing Tests	TBD

UPCOMING FIRING DEMONSTRATIONS

Advanced Sputtered Coatings

U.S. Army Benet Laboratories

ARDEC



120mm XM36 Firing Test #1

- 120mm coated, shrink-fit liner
- July 04

120mm XM36 Firing Test #2

- 120mm coated, shrink-fit liner
- Oct-Nov 04

120mm XM36 Sub-Scale Development & Testing

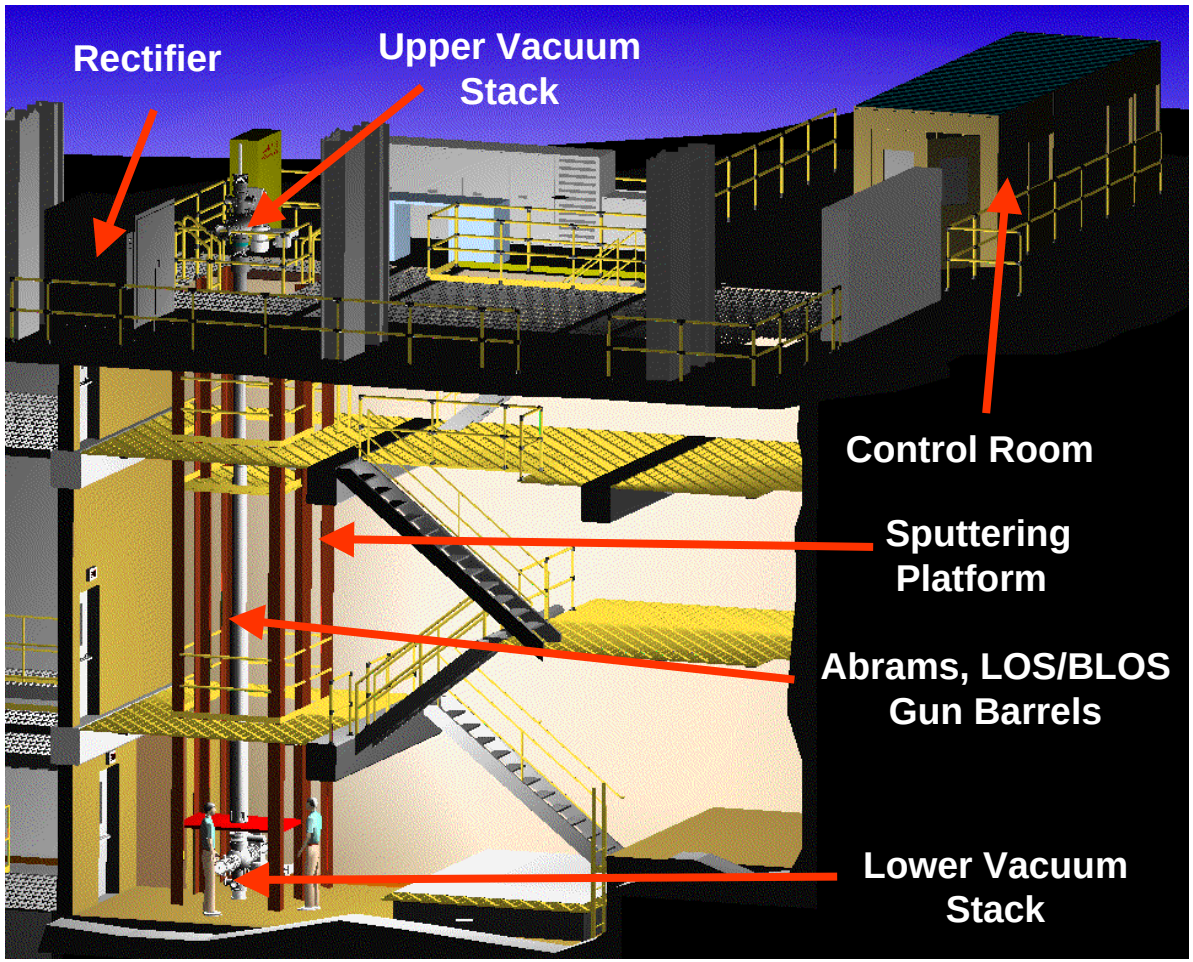
- Full-length monoblock coating test
- Mid FY05

LARGE CALIBER Pre-PRODUCTION Demonstration Platform

at Watervliet Arsenal – Initial Testing - Sep 04

U.S. Army Benet Laboratories

ARDEC



SUMMARY

- **Cylindrical Magnetron Sputtering is a viable alternative to electrodeposition**
- **Cylindrical Magnetron Sputtering results encouraging for large caliber systems**
  - Increased adhesion and bulk properties
  - All laboratory metrics achieved *(still improving deposition rate)*
- **Current 120mm XM36 tests should be insightful**
- **Large Caliber Full-length Pre-Production Platform Initial Testing by Sep 2004**
- **Will one coating technology address all platforms ???**
  - Large Cal vs. Med Cal
  - Autofrettaged vs. Non-Autofrettaged
  - Smoothbore vs. Rifled bore