

Advanced Gun Barrel Technologies (AGBT)

Background and Results

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Outline

- AGBT program background
- Development approach
- Technology selection and screening
- Subscale development and testing
- Full scale firing demonstration
- Summary and conclusion
- Questions

Advanced Gun Barrel Technologies

ONR Future Naval Capabilities Program

Objectives

- Identify & develop Gun Barrel Technologies that enable upgrades to existing barrel capabilities for Naval gun propulsion missions
 - *50% increase in Gun Barrel Erosion & Fatigue Life*
 - *Reduced Life Cycle Cost*
 - *Improved Gun Barrel Thermal and Ballistic Performance*

Payoffs

- Increased Gun System Availability
- Improved Ballistic Capability (Higher KE for increased range)
- Lower Life Cycle Cost

Transition

- Demonstrate Improved Barrel Life and Ballistic performance over AGS Baseline for Transition into DDG 1000

Large Caliber Naval Guns



- **MK 45 / Mod. 2**
- Bore: 5-inch (127mm)
- Length: 54cal, 22.5 ft (6.9m)
- Operating Pressure: 55 kpsi (380 MPa)
- Range: 13 Nmi
- Volume of Fire: 16-20 rnds/min (20 round ready service)
- **Barrel Life: 8000 rnds**
- Thermal Mgmt: Air Cooling
- Mark 67 charge with various projectiles
- Muzzle energy: 10 MJ

- **MK 45 / Mod. 4**
- Bore: 5-inch (127mm)
- Length: 62cal, 25.8 ft (7.9m)
- Operating Pressure: 63 kpsi (435 MPa)
- Range: 41 Nmi
- Volume of Fire: 8-10 rnds/min (10 round ready service)
- **Barrel Life: 1,500 rnds**
- Thermal Mgmt: Air Cooling
- ERM Projectile/Propelling Charge (under development)
- Muzzle Energy: 18 MJ

- **Advanced Gun System (AGS)**
- Bore: 155mm (6.1 in)
- Length: 62cal, 31.5 ft (9.6m)
- Operating Pressure: 53 kpsi (365 MPa)
- Range: 83 Nmi
- Volume of Fire: 10 rnds/min Sustained
- **Barrel Life: 3,000 rnds (Req.)**
- Thermal Mgmt: Liquid Cooling
- Long Range Land Attack Projectile/Propelling Charge
- Muzzle Energy: 27 MJ

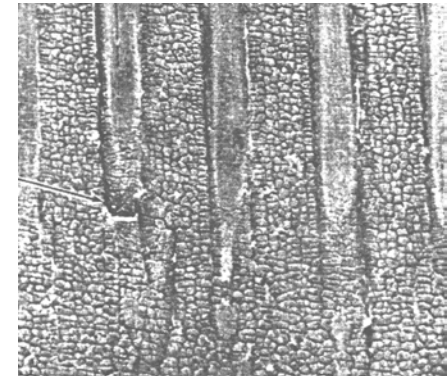
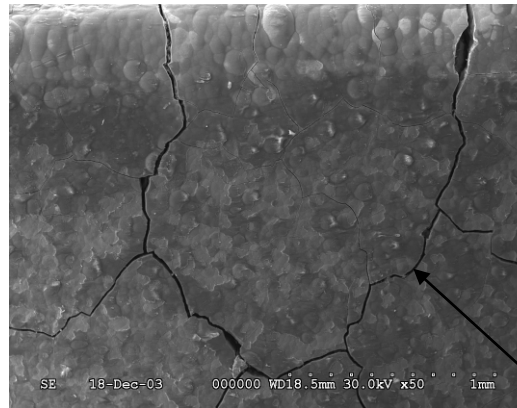
Trend toward higher performance guns using more aggressive propellants

Increased performance levels result in barrel life becoming a logistics cost driver

Current Technology: Hard Chrome

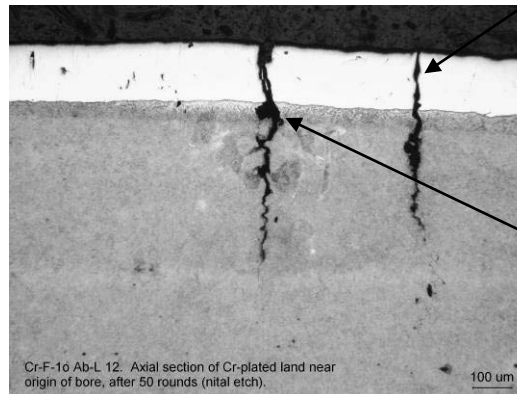
Root Problem: Chrome Plated Barrel Wear and Erosion

- Thermally induced stresses create heat check cracks during firing
- Underlying substrate is thermally altered (HAZ)
- Subsequent chemical attack of steel from combustion gasses undermines chrome
- Chrome “islands” are jeopardized until they break free and leave steel substrate exposed.
- Steel substrate is rapidly eroded by high velocity combustion gasses and accelerated chemical attack at high temperatures.



Bore scope view of heat checks at origin of rifling

Heat Check Cracks



Chrome Plate

Heat Affected Zone (HAZ)

Chemical attack at high temperature undermines chrome

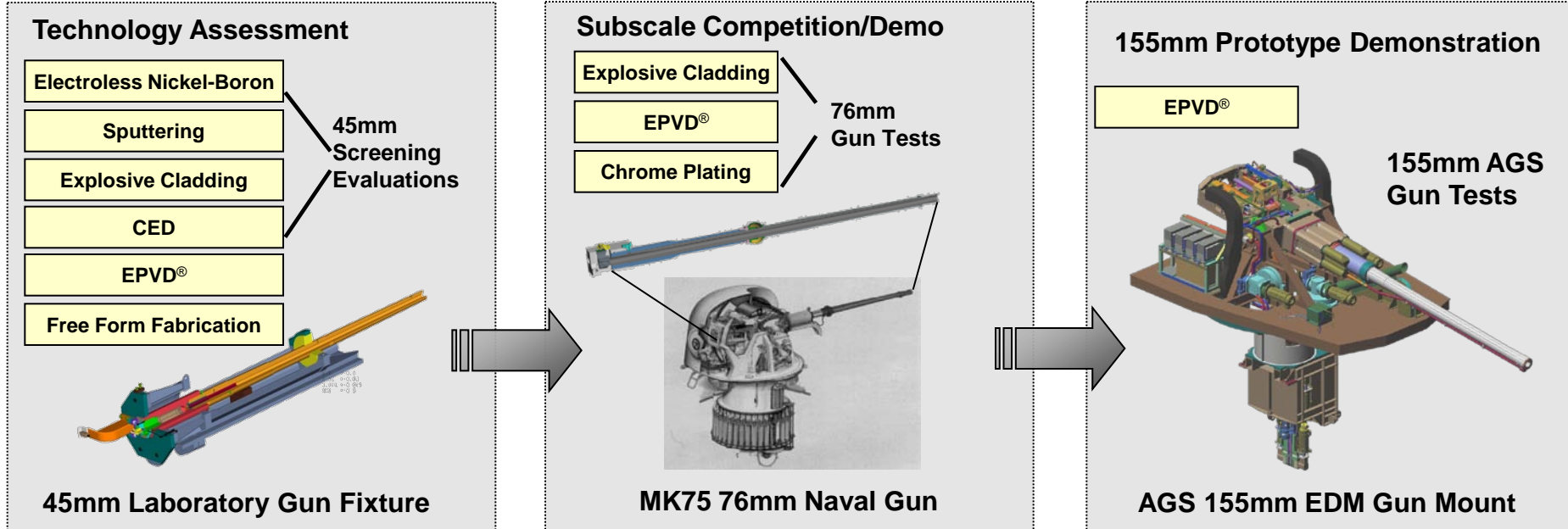
AGBT Development Approach

- Identify existing technologies that have the potential to improve the service life of large caliber gun barrels and can be developed into full scale (155mm) process capability within the time frame of the program
- Screen these technologies using actual gun firings rather than vented combustors or other accelerated wear tests
- Select the most promising technologies for additional evaluation in a high rate of fire environment
- Identify the single best performing technology and demonstrate its performance in full scale 155mm test firings

AGBT Development Approach

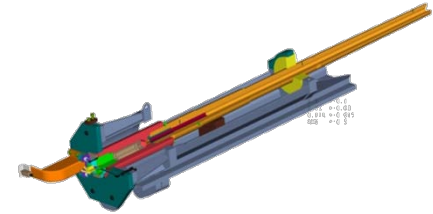
Primary Program Phases

- I. Identify currently available technologies that offer the potential to extend the life and performance of large caliber gun barrels. Screen these technologies through firing tests in a “scaled down” large caliber gun environment.
- II. Select the two most promising technologies for a competitive “shoot-off” in a medium caliber high rate of fire environment.
- III. Select the best technology and demonstrate its performance in a full scale 155mm high rate of fire environment.



Technology Selection and Screening

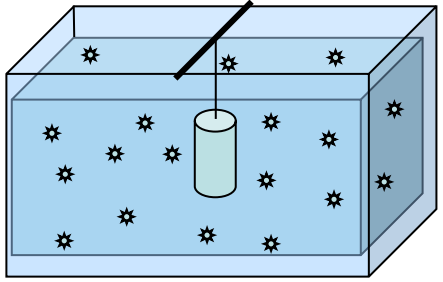
45mm Testing Phase



- Various coating technology vendors were identified
- Vendors of promising technologies were selected to perform under sub-contract
- Vendors applied their coating technology to an insert that was assembled into the shot start region of the 45mm test gun
- Each insert was subjected to a 50 shot test series
- Adhesion results compared to a chrome plated insert 'baseline' using micrographic analysis

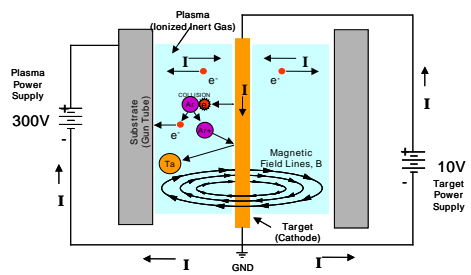
Candidate Coating Technologies

Electroless Nickel-Boron



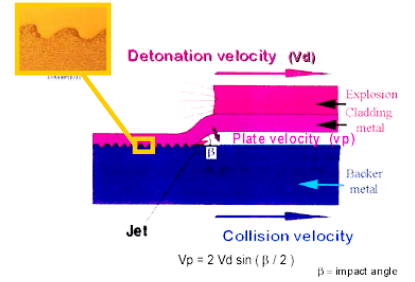
Catalytic plating process produces extremely uniform coating even on complex geometries

Sputtering



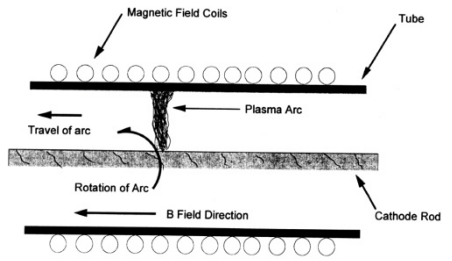
Material is sputtered, from a coaxial target, uniformly over the inside diameter of the barrel

Explosive Cladding



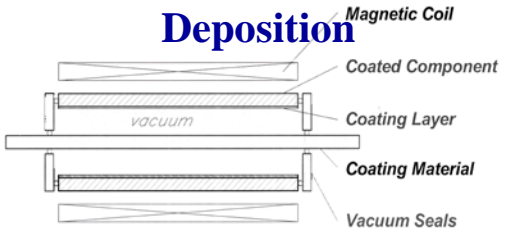
Tube of cladding material is mechanically bonded with the gun barrel in a collision driven by an explosive detonation

Coaxial Energetic Deposition



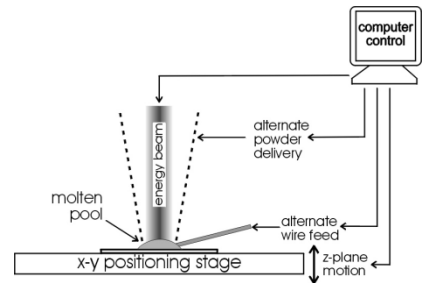
Plasma arc rotates around center conductor and travels along its length depositing material

Electromagnetically Enhanced Physical Vapor Deposition



Electrically controlled magnetic fields enhance the plasma environment of the physical vapor

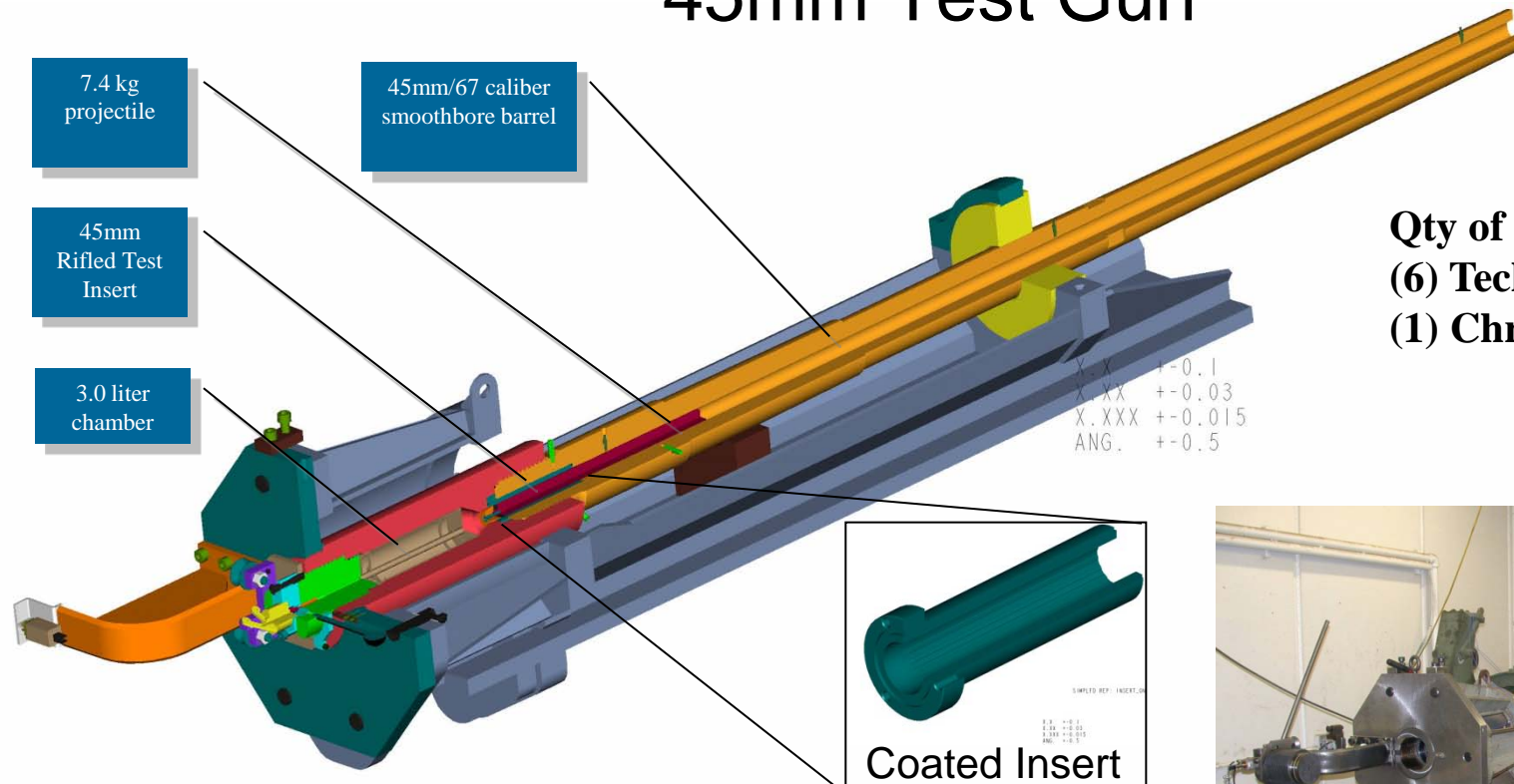
Solid Free-Form Fabrication



Engineered material is created by alloying of powdered and/or wire-fed metals

Technology Screening Platform

45mm Test Gun



Qty of inserts screened:
(6) Technology candidates
(1) Chrome baseline

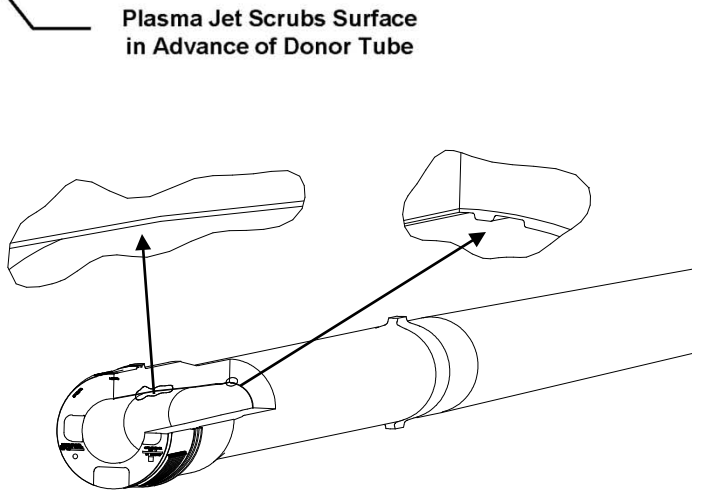
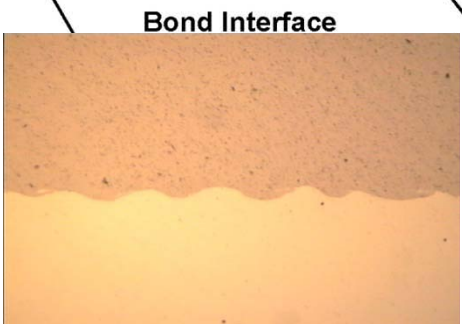
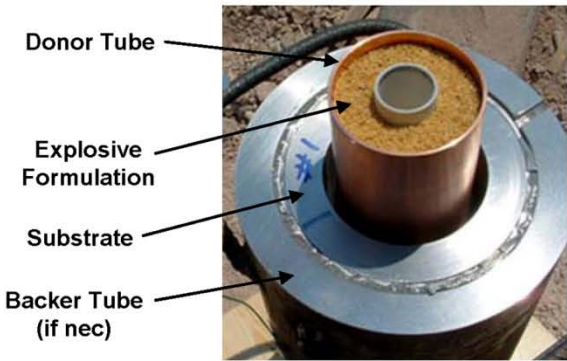
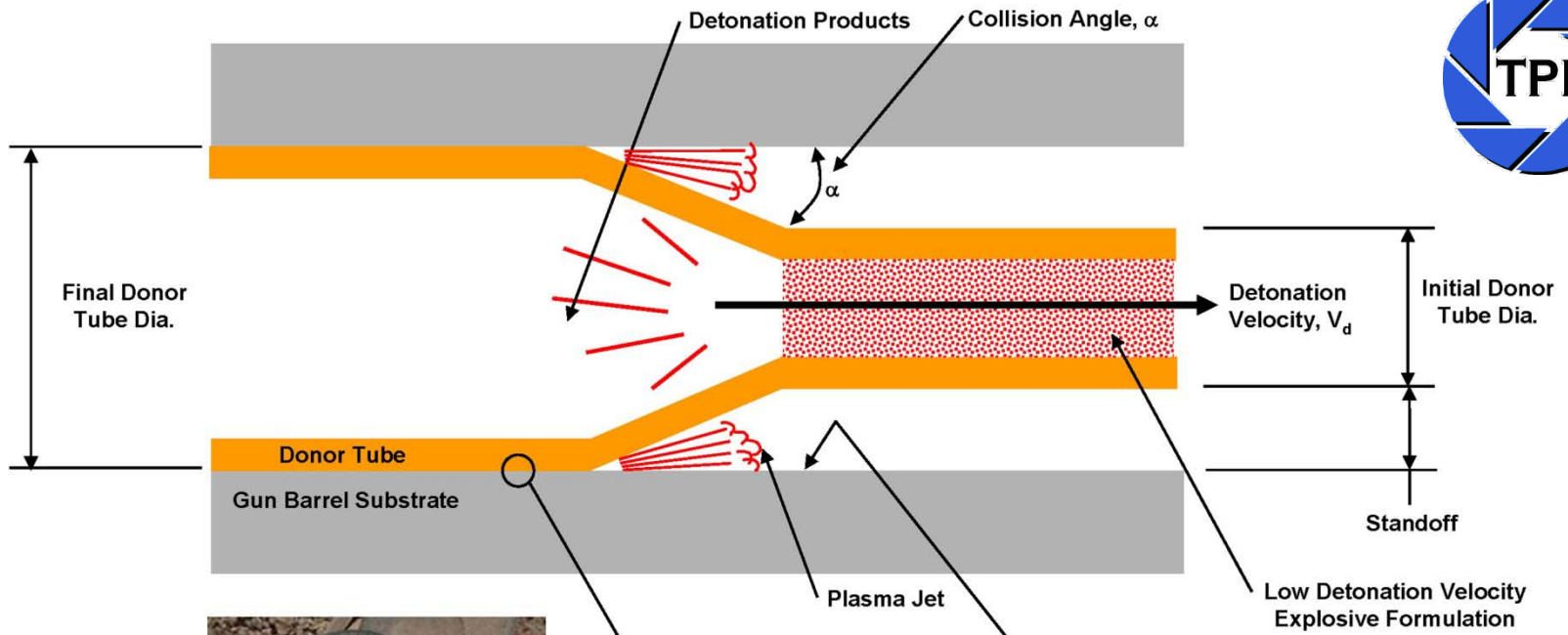
- Coated insert assembled at shot start region of gun
- 45mm ballistics designed to reproduce thermal, chemical and mechanical environment of a large caliber gun
- 50 shot test sequences used to evaluate coating adhesion and integrity
- **Screening Test Winners: Explosive Cladding and EPVD®**



45mm gun in place at BAE Systems test range

Provided a cost effective method for evaluating coatings prior to large caliber gun evaluation

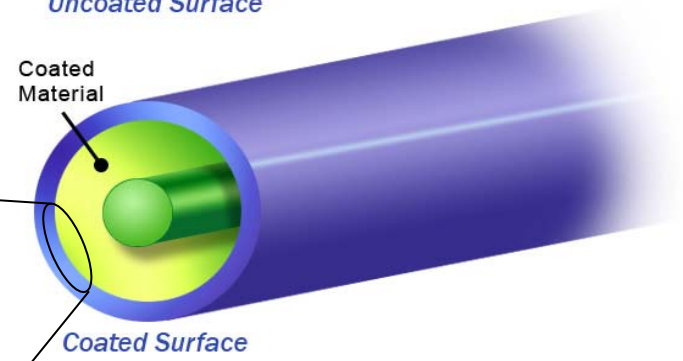
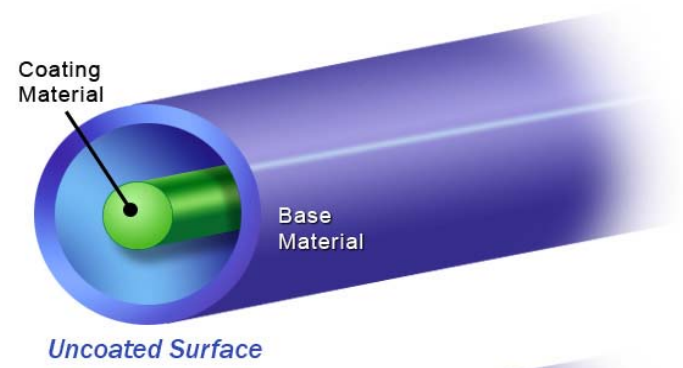
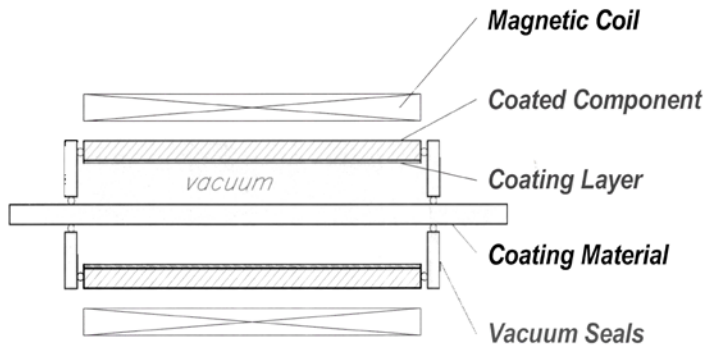
Explosive Cladding Process



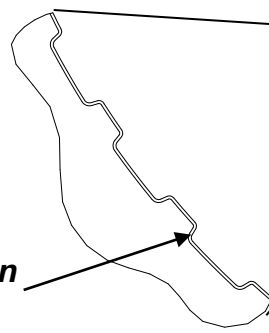
EPVD[®] Process

(Electromagnetically Enhanced PVD)

Electromagnetically Enhanced Physical Vapor Deposition (EPVD[®])



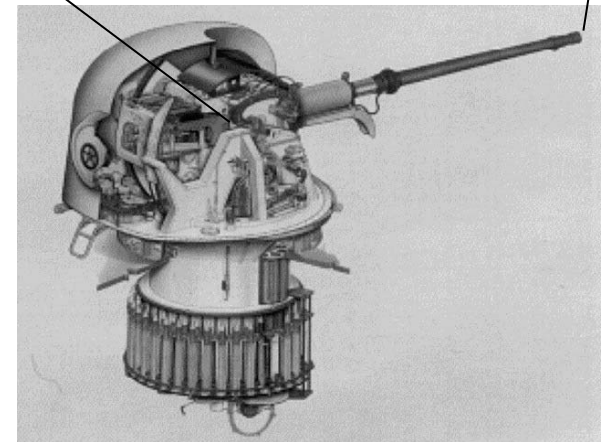
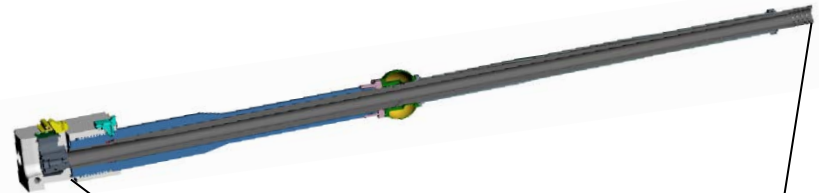
Uniform thickness on lands and grooves



76mm Medium Caliber Testing

- 76mm platform selected for similar match to the AGS near bore thermal profile
- Historical 76mm service records indicated that measurable wear and erosion would occur within 400 rounds fired
- Technologies were applied to the bore of MK 75 gun barrel liners for firing at rate for a total of 400 rounds each. A chrome plated 'baseline' liner was subjected to the same test.
- 76mm tests were conducted at the Naval Surface Warfare Center, Dahlgren Division (NSWCDD).

Prototype Barrel Assembly For Mk 75 76mm Gun

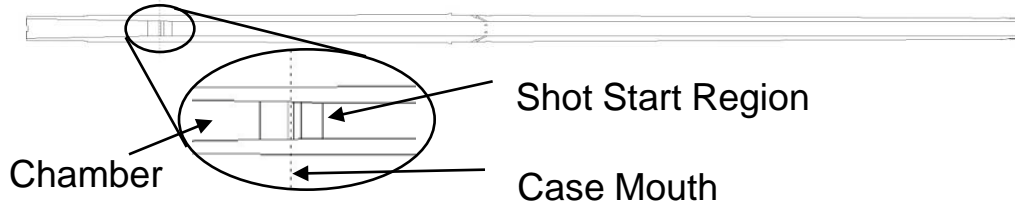


76mm Rapid Fire Testing

- Explosive clad liner experienced problems in manufacturing that were not recoverable within the time frame of this program and therefore effort was ceased
- Chrome Baseline and EPVD[®] coated liner were subjected to 400 rounds each, at max rate of fire in Mk 75 Naval gun
- Each liner was subjected to ten 40 round bursts at ~90 rounds per minute
- Detailed inspections conducted every 80 rounds

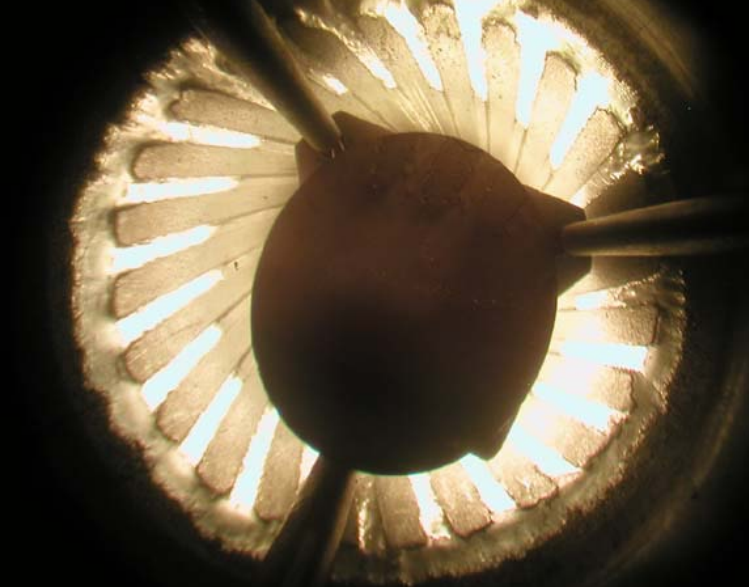


76mm Post Test Inspection

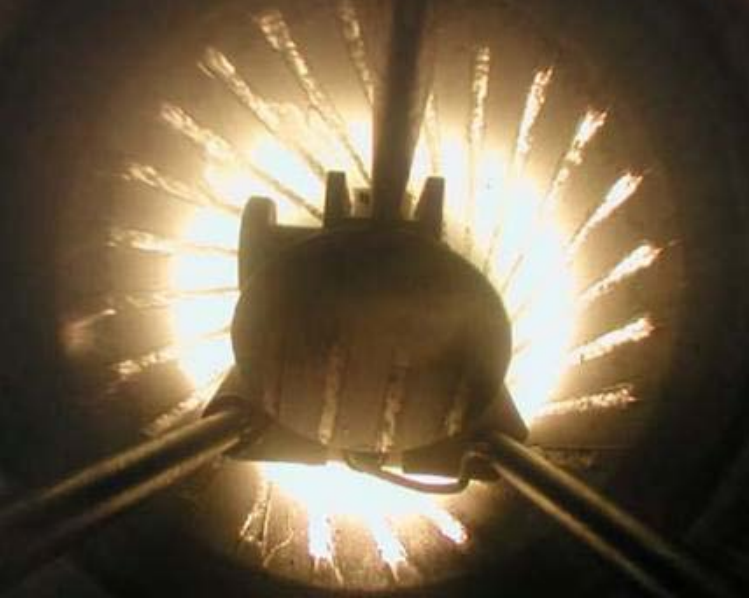


- NSWCCD bore scope reports at conclusion of test
 - Baseline Chrome
 - “Heavy erosion is present in the origin of bore and origin of rifling area”
 - EPVD® Ta-W
 - “Moderate erosion exists in the Origin of Bore area”
- *In both cases, coating removal from lands is due to engraving loads of gilding metal rotating bands.*
- EPVD® erosion much less than Chrome

Baseline Chrome Plating

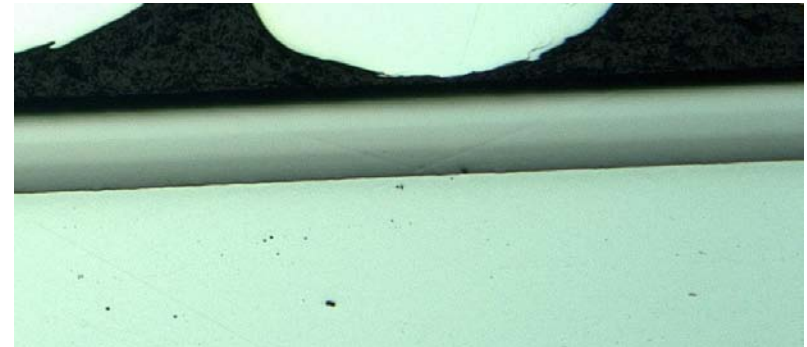
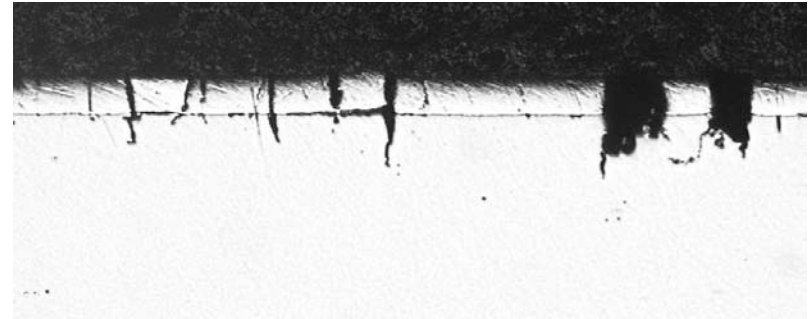


EPVD® Ta-W Plating



Micrographic View of Coatings

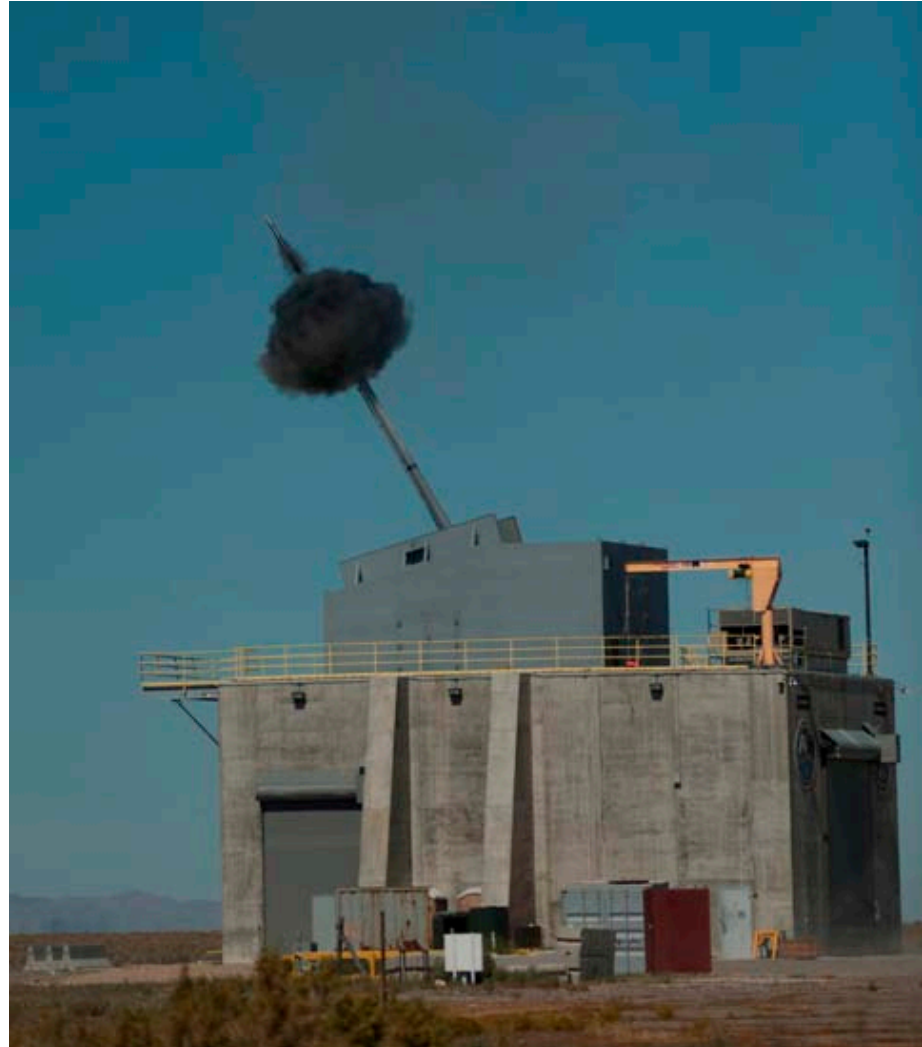
- Chrome plating shows significant heat check damage with cracks extending up to 1mm deep in substrate
- EPVD[®] shows a thicker coating layer without apparent cracking or obvious heat affected zone



EPVD[®] applied Ta-W coating was well adhered and provided excellent thermal and chemical protection

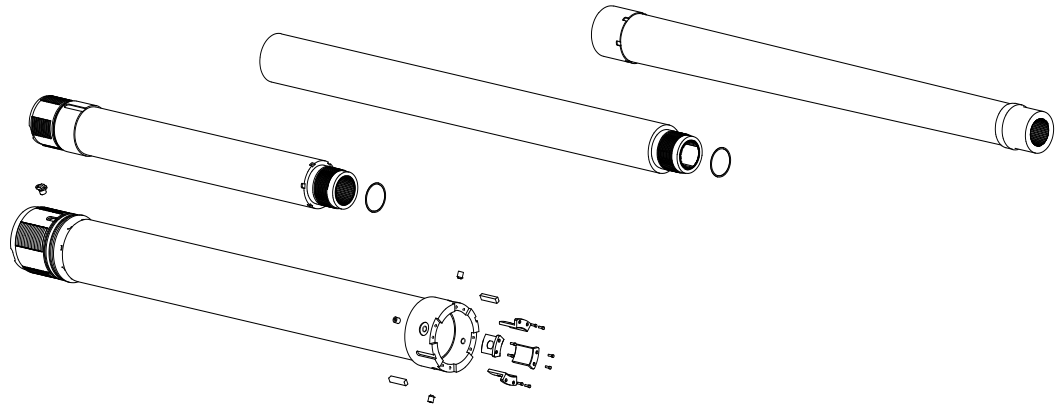
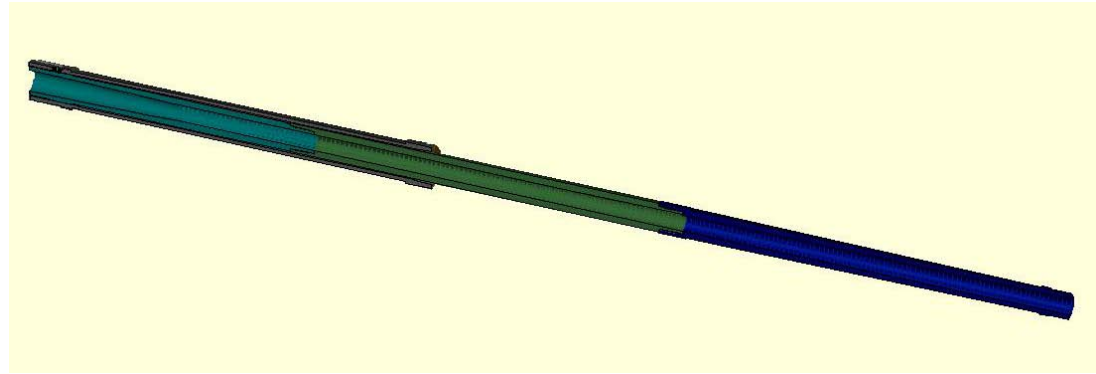
Full-Scale 155mm Demonstration

- Full scale tests conducted using the BAE Systems Advanced Gun System (AGS) Engineering Development Model (EDM) mount at Dugway Proving Grounds, Utah
- A multi-piece 155mm barrel was used for AGS rapid fire testing
- Barrel was subjected to Proof shots as well as extended firing at 10 rounds per minute



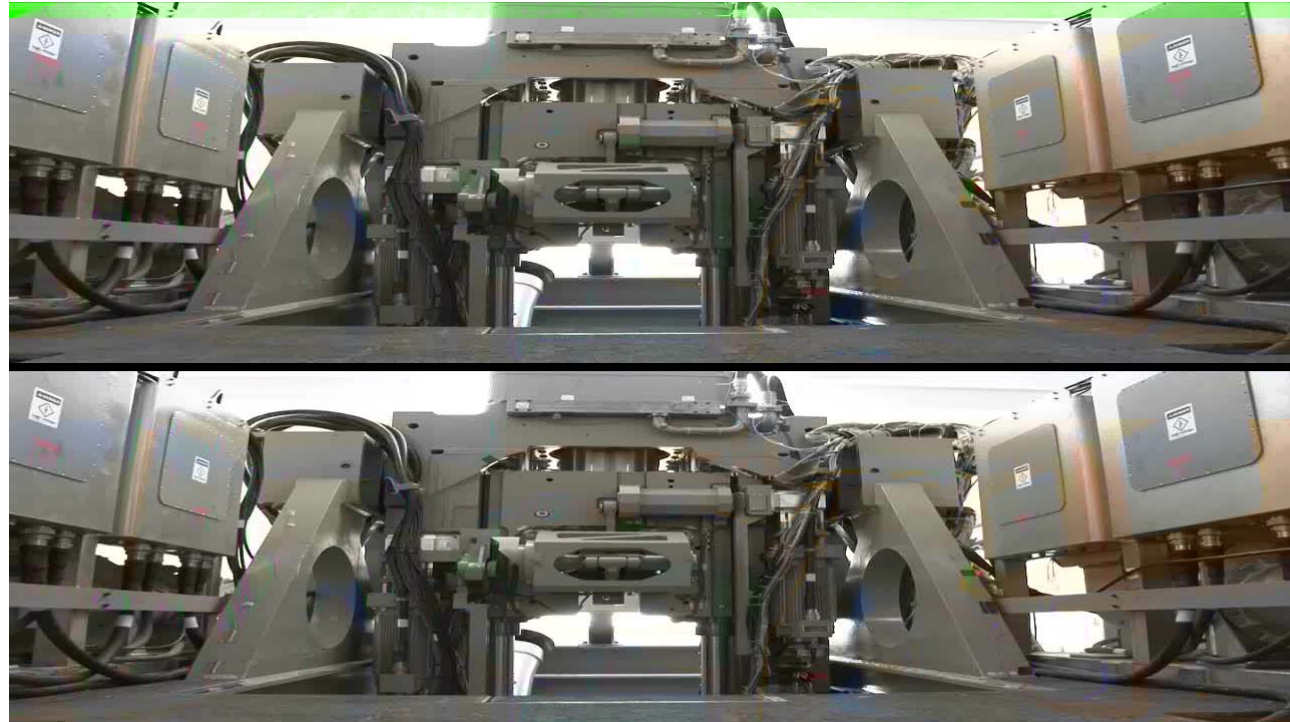
Tube and Liner Barrel Assembly

- AGBT test barrel is a tube and liner assembly
- Liner is a multi-piece subassembly
 - Allowed barrel to be fabricated from available assets
 - Allowed barrel to be coated using existing equipment
- Integrates with the EDM mount using existing cooling hardware



155mm Development

- Advanced Gun System (AGS)
 - 155mm (6.1") 62 cal.
 - 10 rounds/min.
 - Vertical load
 - Liquid cooled
 - All electric drives
 - Fully Automated Magazine
- 61 total shots fired in AGBT test series



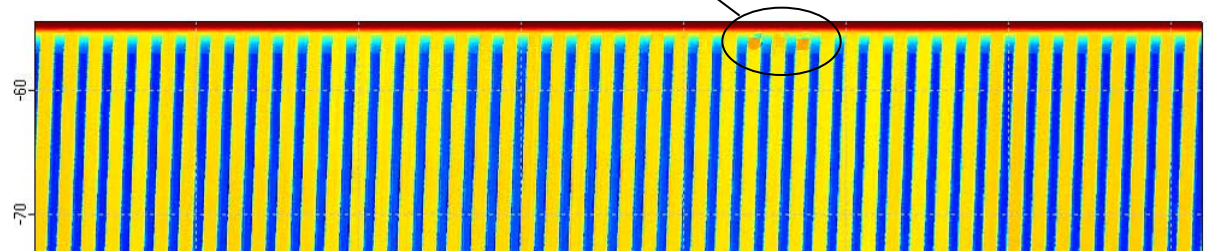
Laser Scan data of Shot Start Region



Note: area of delamination

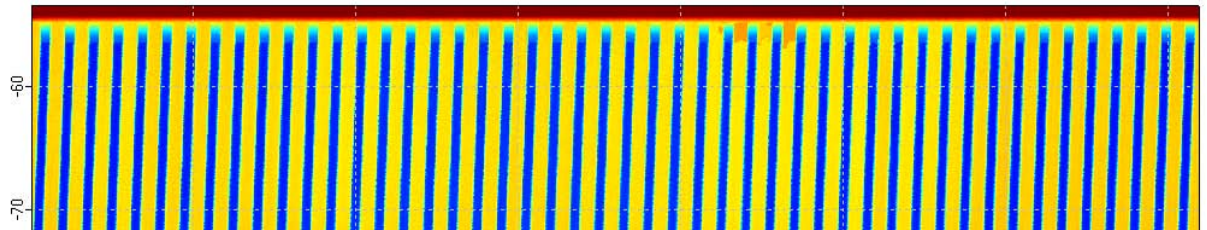
Shot 0

Coating delaminated in
noted area prior to firing



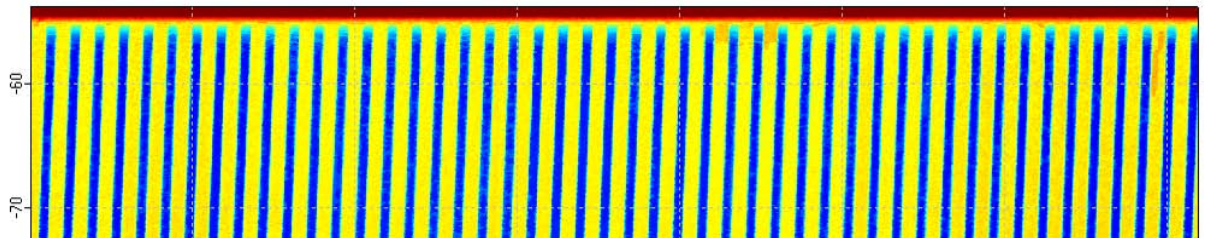
Shot 8

At conclusion of proof
series, delaminated area
grew slightly



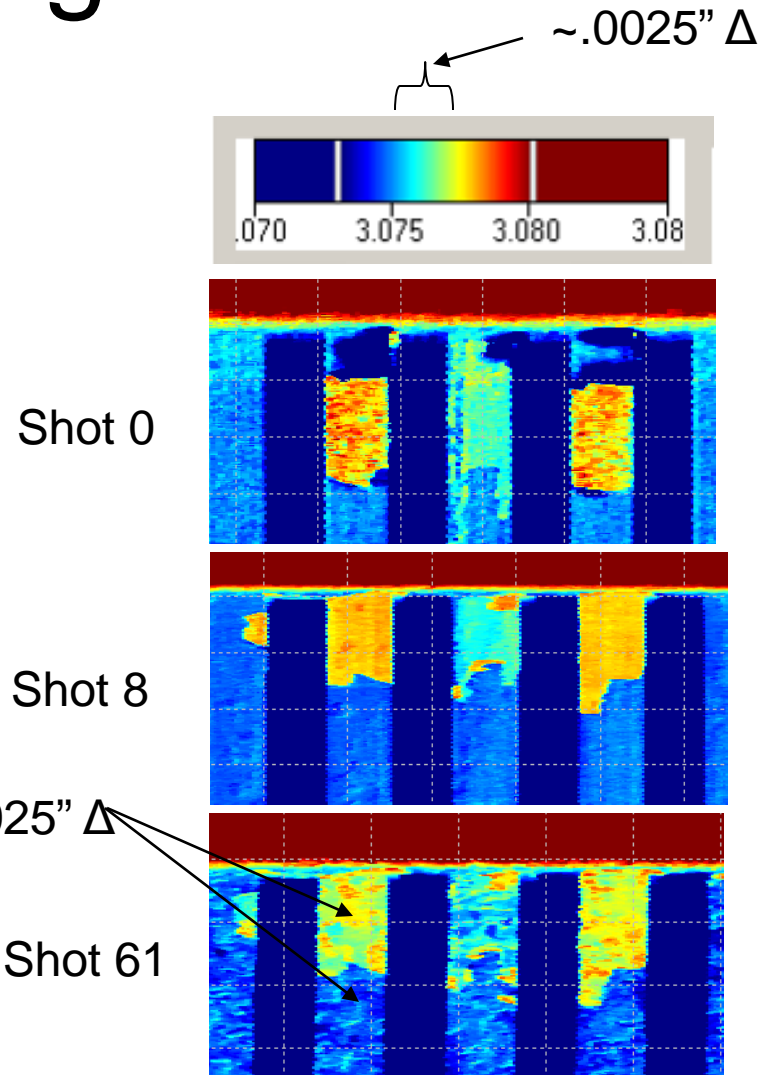
Shot 61

At conclusion of rapid
fire series, minimal
additional grown.



Degree of coating loss

- Localized area at origin of rifling shows loss of the upper most layer(s) of the coating in three adjacent grooves prior to firing.
- Damaged area does not grow appreciably during the firings
- Laser based profilometry used to determine depth of features. Accuracy: +/- .0005"
 - Full depth of coating is .005" thick
 - Coating delamination: ~.0025" deep
- Substrate is not exposed, damage appears limited to top layer(s)
- Barrel not removed for micrographic analysis of coating.



Conclusion: EPVD[®] coating adhesion to barrel substrate held-up during firing tests. Work still needed to address inter-coating delamination

Summary and Conclusions

- AGBT Program successfully met objectives
- Selected technology: EPVD[®]
- Improvements in coating composition needed to tolerate mechanical engraving loads of gilding metal rotating bands
- Improvements in processing needed to address interlaminar adhesion
- Application of EPVD[®] technology for gun barrel use is relatively new. Potential for different compositions of various materials exists
- BAE Systems is currently working with the U.S. Navy to transition this technology for fleet use

Questions

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