M789 LW 30mm HEDP Cartridge In-Bore Detonation Investigation

Presented By

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Agenda

- 30mm Inbore/Hangfire Investigation
  - Apache M230 Weapon System Basic Information
  - Reported Problems
    - Total Incident Types / #'s & Groupings
    - Resultant Damage Examples
  - Investigation Team
  - Methodology Employed
  - Most Likely Causes & Actions Taken
  - Additional Recommendations
  - Summary

Apache M230 Weapon System

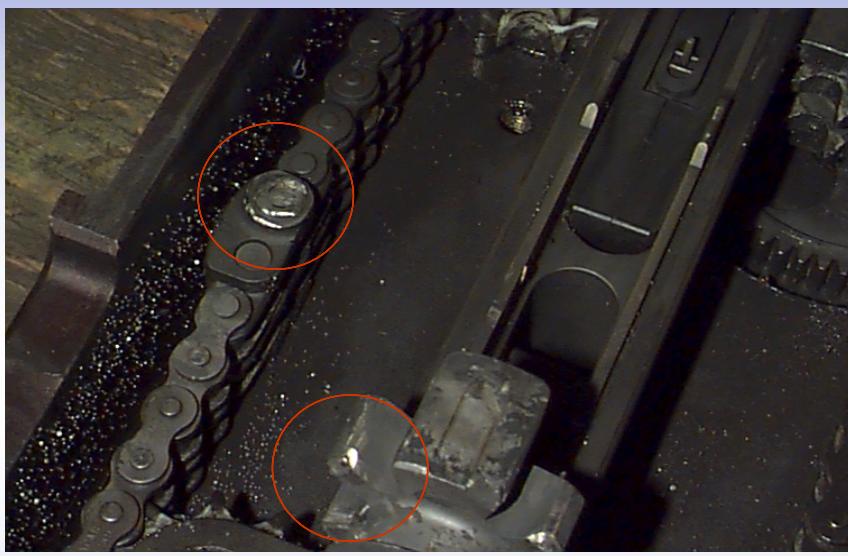
- Aircraft System
  - Turret Mounted Weapon
  - Closed Loop Linkless Feed System
  - Weapon Mounted Uploader/Downloader; 'D' Model Aircraft have Additional Ammunition Sideloader
  - First In/Last Out Ladder/Rail Magazine
- M230 Weapon
  - Externally Powered w/Electric Drive Motor
  - Single Barrel, Chain Driven Automatic Cannon
  - 625 ± 25 Shots per Minute Firing Rate
- M789 High Explosive Dual Purpose Cartridge
  - Aluminum Cartridge Case w/Electric Primer, IB52 Booster System & Double Base WC855 Ball® Powder
  - High Strength 4130 Steel Projectile w/PBXN-5 Explosive Fill
  - Spin Compensated Shaped Charge Liner
  - Point Initiating, Base Detonating Nose Mounted Fuze

Original Incident Classifications

- Hangfire – Ballistic functioning of the cartridge occurs outside of the dwell time of the weapon. Operating group & sometimes receiver damaged.
  - 23 Incidents since Aug 97
- Inbore Detonation – Premature initiation in the barrel under the barrel support shroud. Barrel bulges, sometimes ruptures.
  - 21 Incidents since Aug 97
- Severed Barrel – Premature initiation in the barrel near the muzzle. Muzzle is completely lost.
  - 2 Incidents Since Aug 97

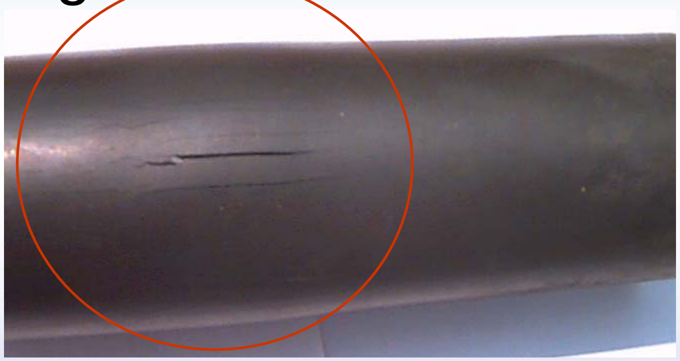
Typical Damage
"Minor Event" - Hangfire

Typical Damage
"Severe Event"- Hangfire



Typical Damage
Inbore Detonation

• Damage Similar to or Identical to Severe Hangfire/High Pressure Plus Barrel Cracking & Muzzle Break Impacts by Fragments

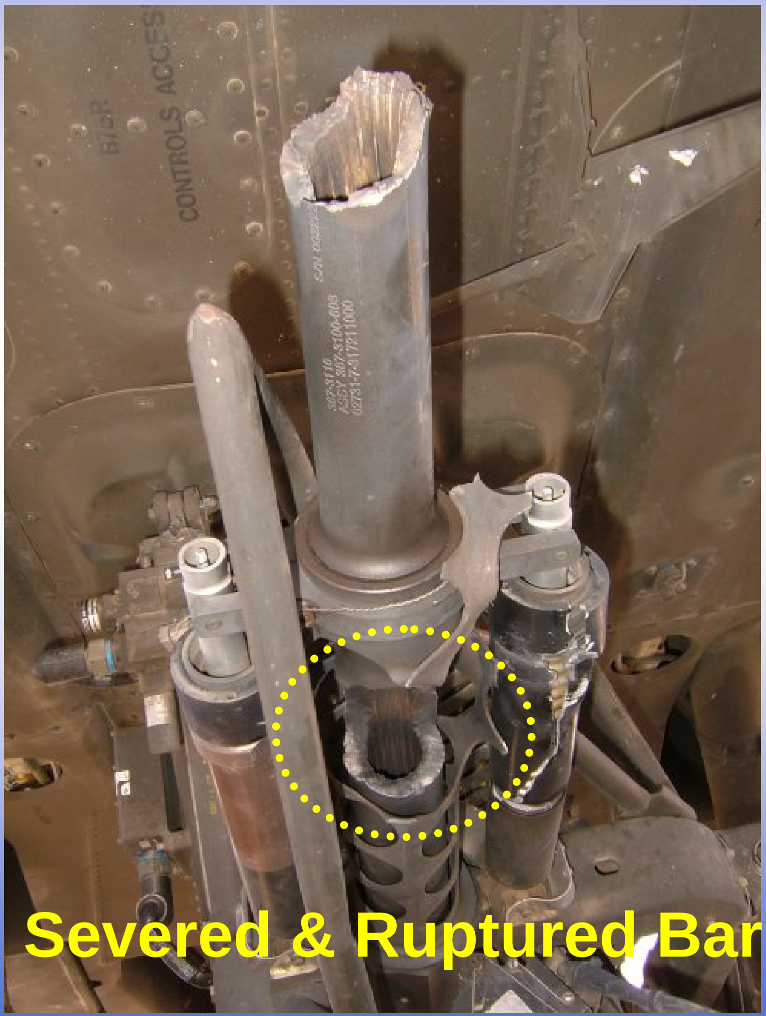


Typical

Extreme

Typical Damage Bullet on Bullet

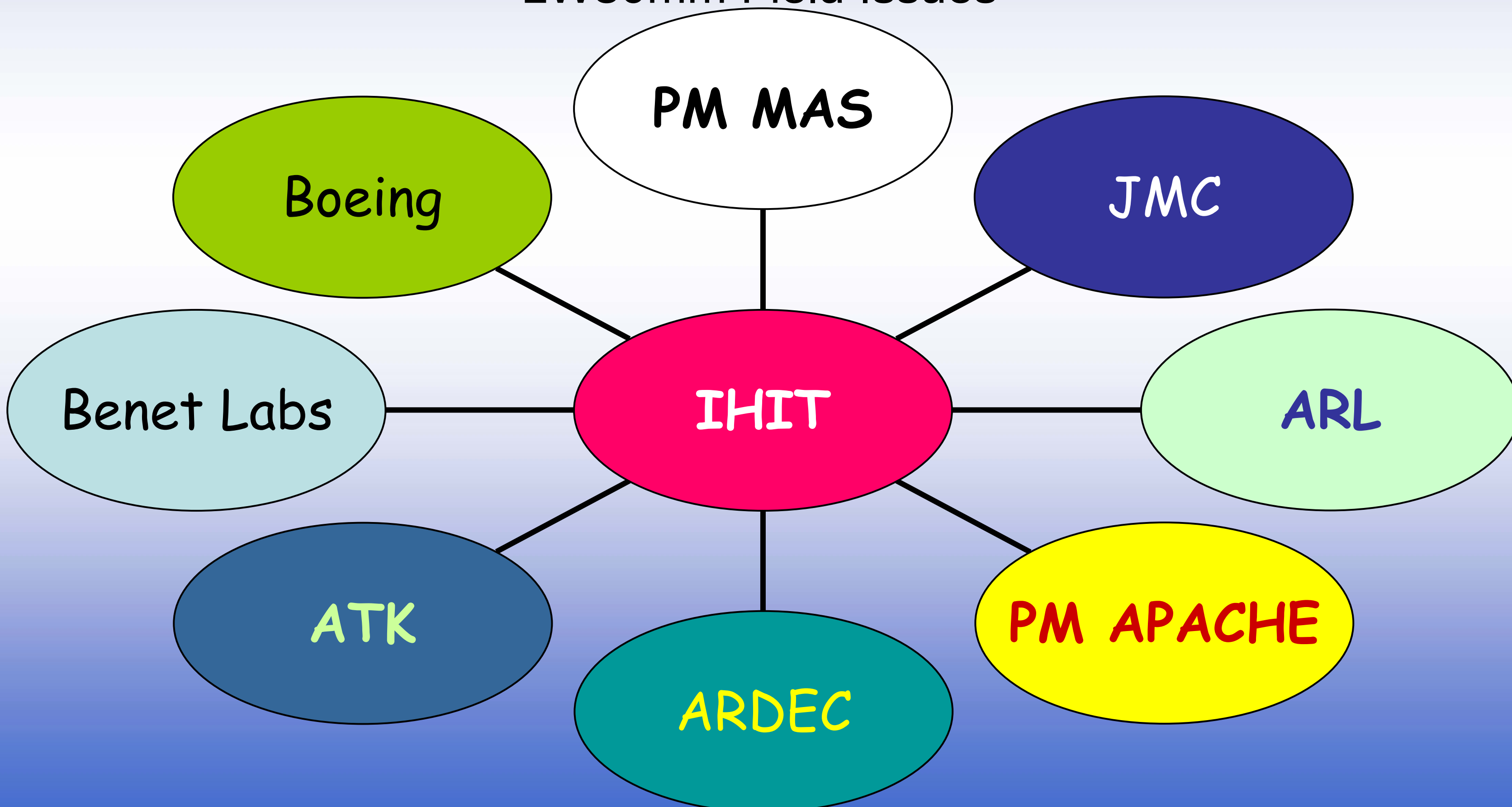
1/130th



2/101st

In-Bore/Hang-fire Investigation Team Participation

In-Bore/Hang-fire Investigation Team Encompasses Elements From Across Area Weapon System, and is a Total System Approach to Solving LW30mm Field Issues



IHIT Methodology

- Team Used A System Engineering And Six Sigma Approach
  - Interviews w/Field Units (Shooters, Ground Crews, Supply)
  - Re-work Previous Root Cause Analysis for Inbore Detonations
  - Use Failure Mode Effects Analysis (FMEA) Process
  - Collect Data (Modeling, Simulation, Testing) To Fill Data Gaps & Populate Fault Tree For Each Failure Mode
  - Conduct Design Of Experiments (DOE) And Verification Testing
  - Incorporate Changes Into TDP

UNIT VISIT & INCIDENT KEY INFORMATION

- No Incident Resulted from the 1st Round Fired
- Ammo Usually Stays in A/C Until Scheduled Phase Maintenance - Some Units Reloaded in Reverse Order of Download
- Manual Mode for Sideloader & Uploader/Downloader are Still Used Infrequently
- Feed System Jams While Uploading are Still Occurring Resulting in Punctured Cartridge Cases

A Total System Approach

- Cross Functional/Cross Organizational IPT
- Co-Leaders from PM-MAS & PM-Apache
- User Involvement & Feedback
- Systems Engineering

Cannon, Handling System & Aircraft Systems
121 Potential Causes

215 Total Potential Failure Modes Identified

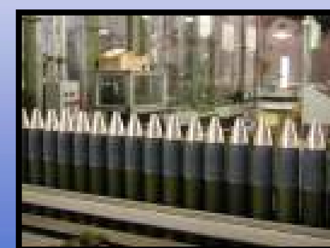
Ammunition Handling & Storage
3 Potential Causes

Six Sigma Tools:

Continuous Black Belt Consultation
Failure Modes Effect Analysis
Fault Tree Analysis
Design of Experiments

Ammo Metal Parts Manufacture
55 Potential Causes

Ammunition LAP
36 Potential Causes



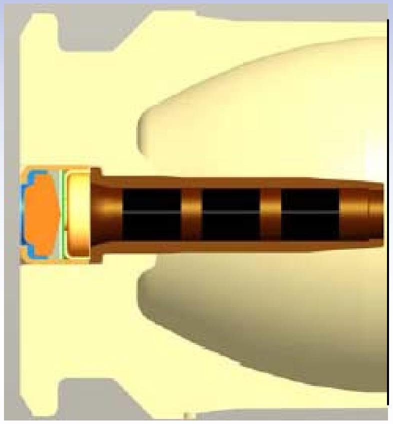
Identified Three Major Root Causes

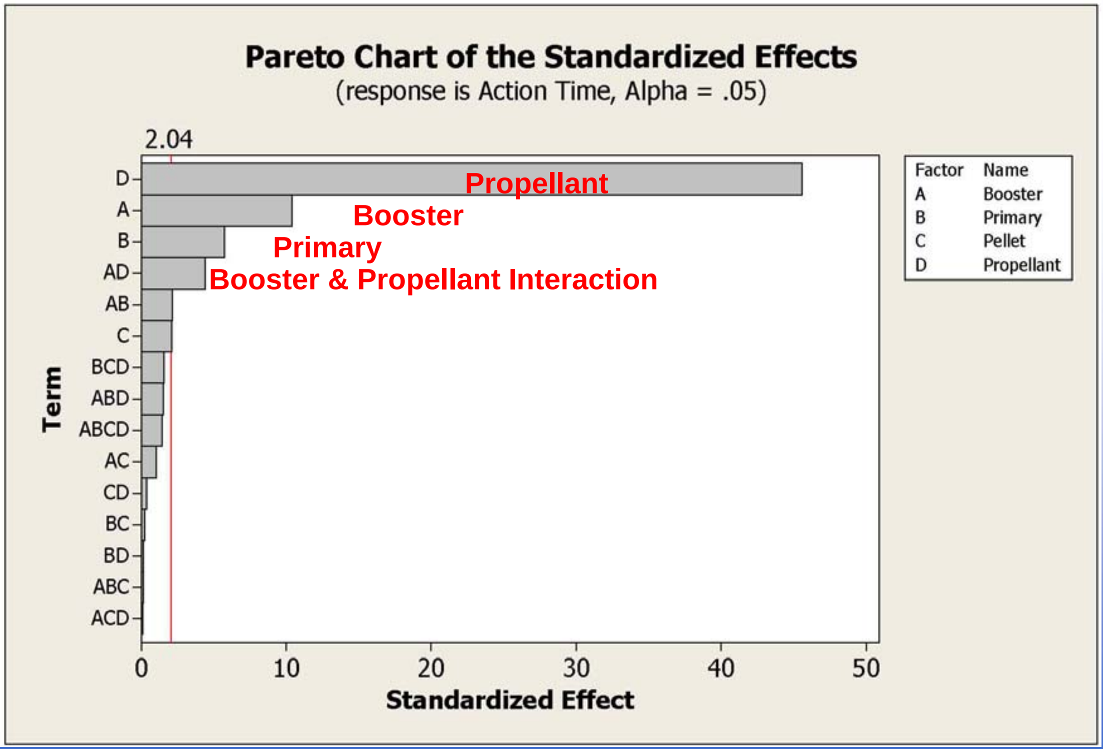
Hangfire/High Pressure

Ignition System DOE Phase I

Control Factors	Level 1	Level 2	Level 3
Booster Mix	100%	50%	
Primary Charge	With	Without	
Flashtube Pellets	Pellet	Powder	
Propellant Level	100%	50%	25%

MANN BARREL TEST





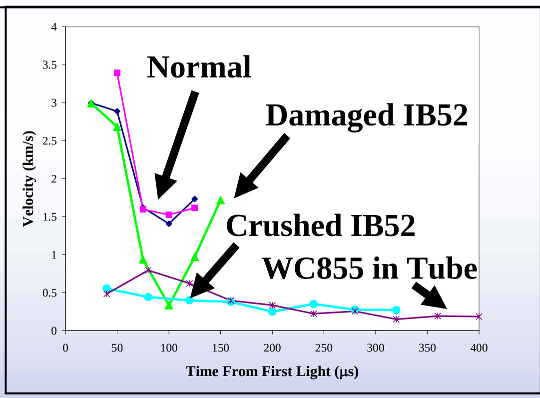
Damaged IB52 Pellets/Flash Tube

Open Air High-Speed Video of Flash Tube Venting

Normal Flash Tube

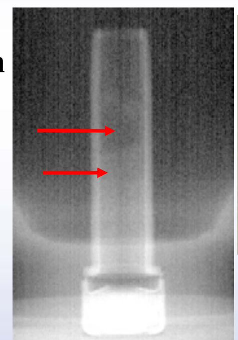
Damaged IB52

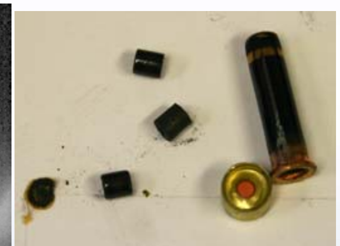
WC855 in Tube



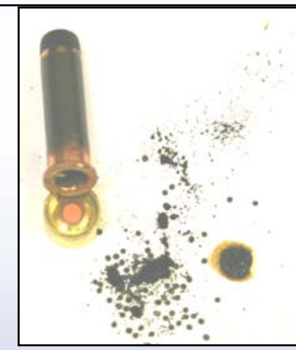
Gas Velocity From Flash Tube

Radiograph Damaged Flash Tube in M789



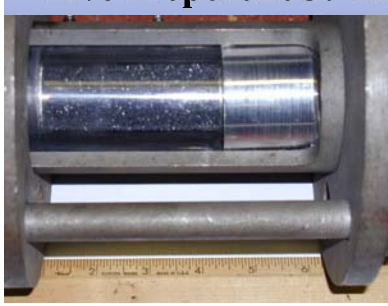


Some Damage IB52 Pellets

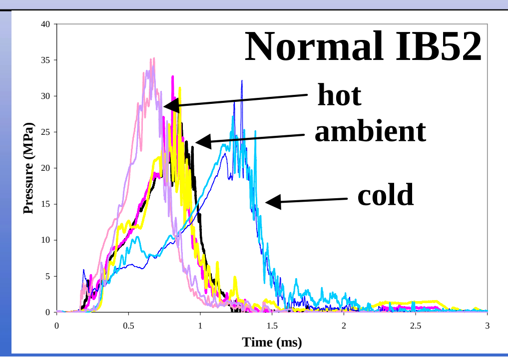


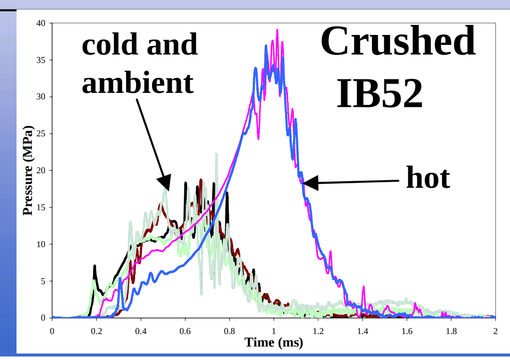
Broken Lacquer Seal with WC855 in Tube

Live Propellant 30-mm Gun Simulator



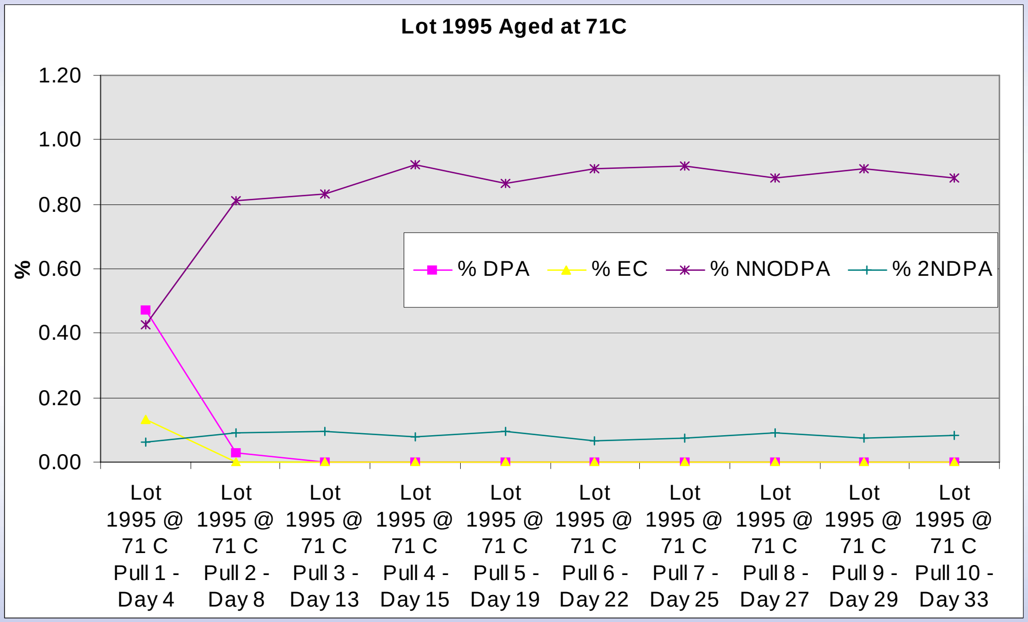
WC855 in Flash Tube has Given Greater Than 40 ms Ignition Delay

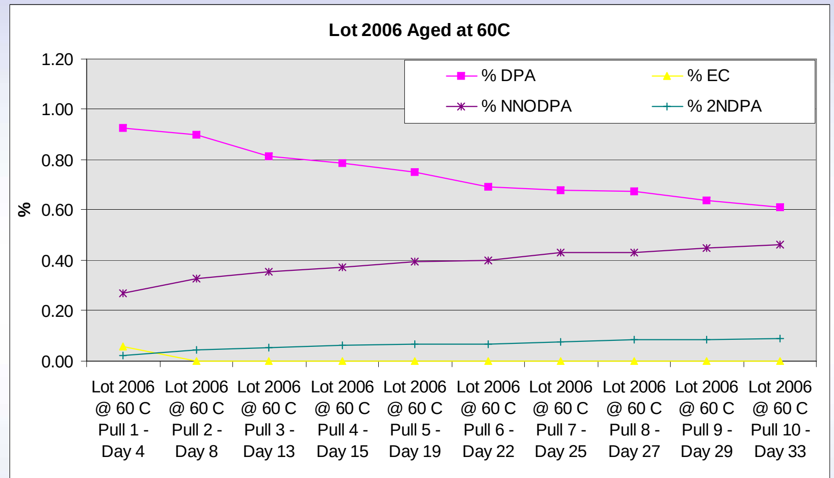


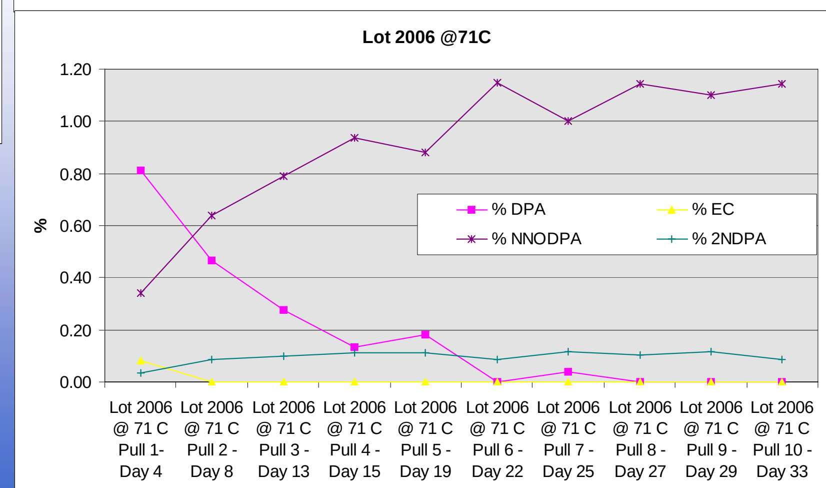


Hot Temperature Storage Led to DPA Depletion

- Over time, the original stabilizer, DPA, depletes and converts to daughter products – 2NDPA, NNODPA ; DPA reaction rate increases as temperature increases





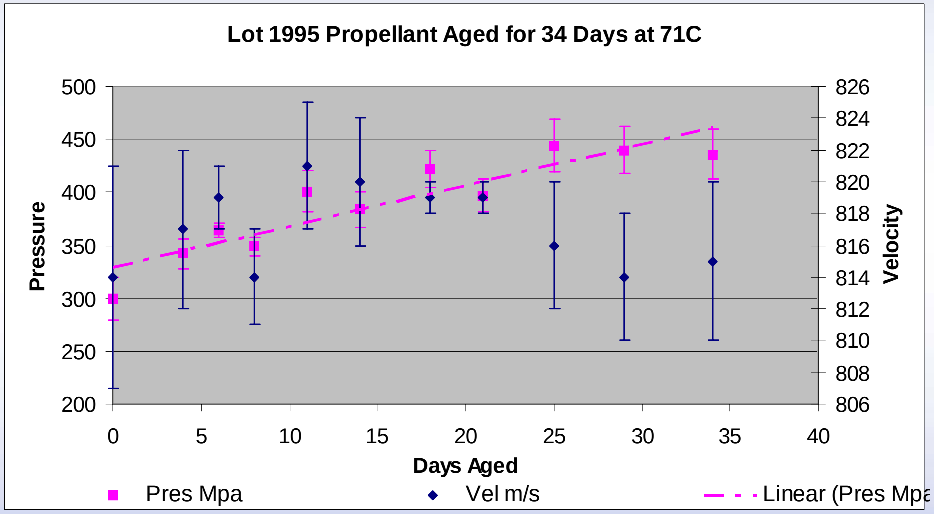


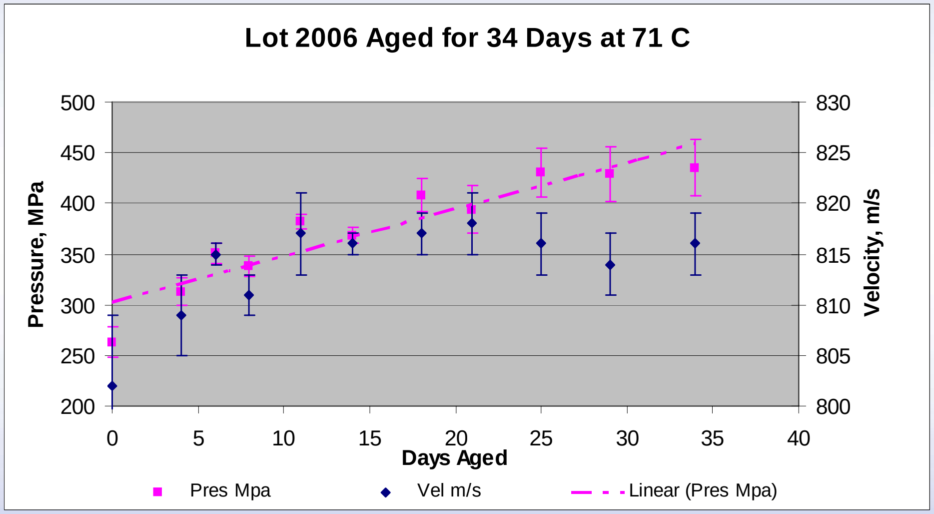
•DPA concentration of the 1995 Lot had depleted to half the concentration of the 2006 Lot at time = 0

•AT 71°C, DPA concentration depleted to 0 within 22 days of storage

Ballistic Pressure Increases With Days Aged

•**Within 10 days of aging a new propellant lot at 71°C, the measured pressure was in excess of the upper specification limit of 335 MPa**



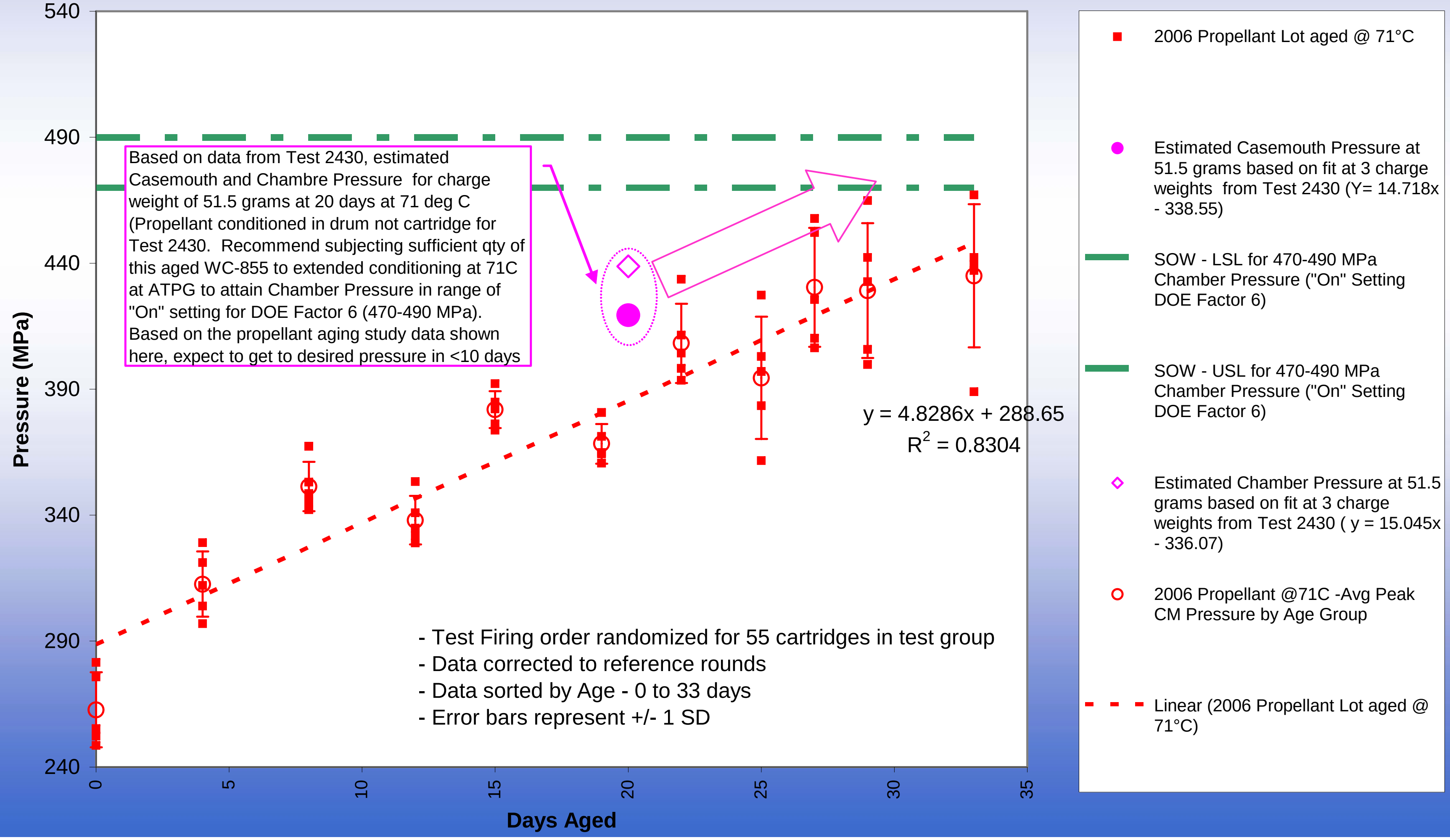


•Ballistic testing conducted at ambient. All data corrected with reference ammunition. Data is the average of 5 shots.

•Variation in pressure performance attributed to migration of DBP deterrent

Aged WC-855 for DOE Factor 6

Casemouth Pressure vs Days Aged - 2006 Propellant Lots Conditioned at 71 deg C
(Test RFAAP 07-004 & 005)
IHIT Propellant Aging Study - Ballistic Testing at Radford 4-5 January 2007



Headspace DOE

Phase I Test Matrix

Firing Order of Rounds	No. of Rounds	High Pressure (approx 500 Mpa)	Nominal Pressure	Nominal Headspace	Headspace 0.025”	Headspace 0.031”	Hot Barrel (180ºF)	Ambient Barrel
1	5		X	X				X
2	5	X		X				X
3	5	X			X			X
4	5	X				X		X
5	5		X		X		X	
6	5		X			X	X	
7	5	X			X		X	
8	5	X				X	X	

Tested ok

Incident 1

Incident 2

Phase II Test Matrix

Firing Order of Rounds	No. of Rounds	High Pressure (approx 415 Mpa)	Nominal Headspace (.022”)	Maximum Headspace (0.031”)	Ambient Barrel
1	5	X	X		X
2	5	X		X	X

Headspace DOE

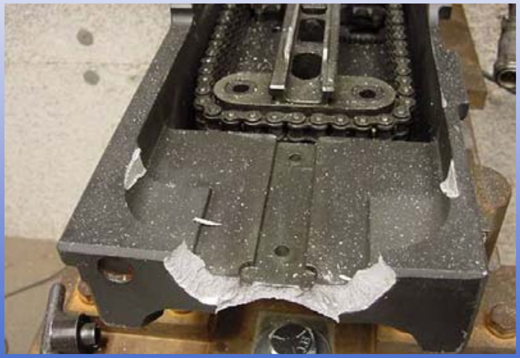
•**Hangfire signature has been replicated <u>without</u> an actual hangfire event.**

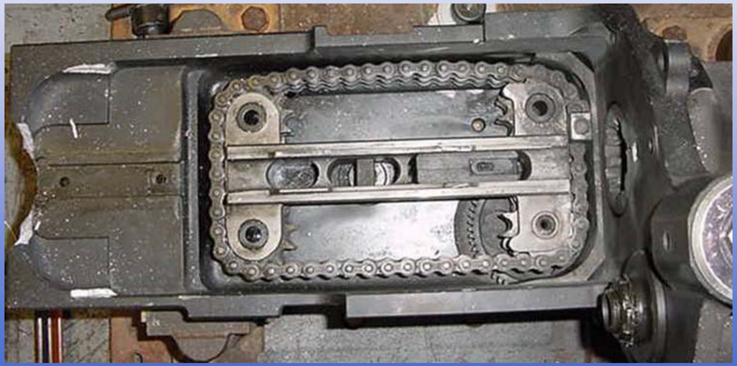
Excessive headspace
Elevated pressure (~ 500 Mpa)
Hot barrel

•**Propellant gases vented from the chamber area can damage the operating group and receiver.**

•**Damage created similar to that seen in HE-Inbore events, except no barrel bulge and generally no Blast Suppressor damage.**

•**Not all “hangfires signatures” are necessarily actual hangfires.**





Hangfire/High Pressure

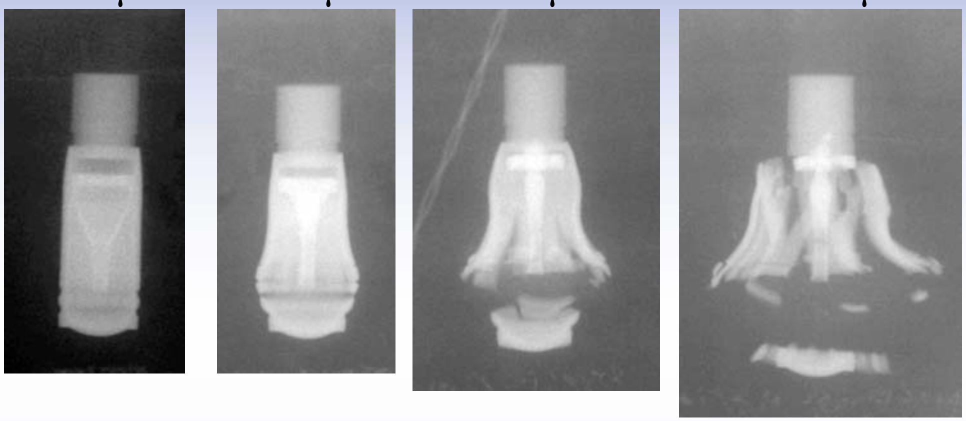
- Most Likely Causes
  - ★ Extended Vibration Damages Cartridge Ignition System (Replicated)
    - No Rounds Showed Physical Damage After 144 Hours
    - 30% Showed Some Damage After 192 Hours
  - ★ Extended High Temperature Exposure Changes Propellant Characteristics (Replicated)
    - Significant Pressures Measured after 432 Hours @ 71º C (160º F)
  - ★ Cartridge Cases are Punctured and Propellant is Lost or Contaminated (Replicated)
- Actions Taken to Date to Reduce/Eliminate Issues
  - 1980s Production Placed into Condition Code 'N'
    - Removed to Strategic Reserve in Kuwait, Planned for Demilitarization When Stockpile has been Replenished
  - Aviation Safety Action Message (ASAM) and AIN issued
    - Requires Download and Inspection of Ammo at Aircraft Regularly Scheduled Maintenance
    - Requires Rotation of Ammo When Reloaded into Aircraft to Minimize Prolonged Exposure to Vibration and Extreme Temperatures
  - Initiated Design Improvement Program to Improve Robustness of the Ignition Train

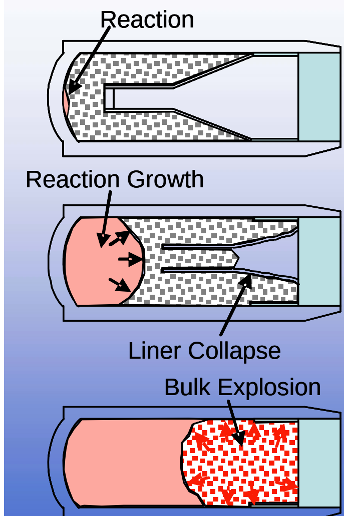
Inbore Detonation

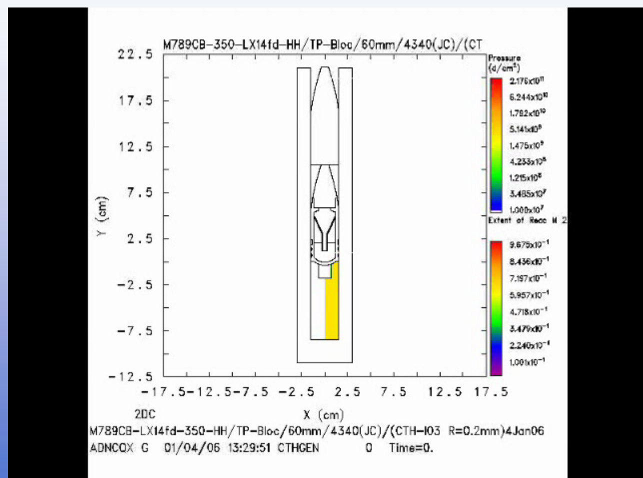
Explosive Reaction and Response

Low Order Time Lines

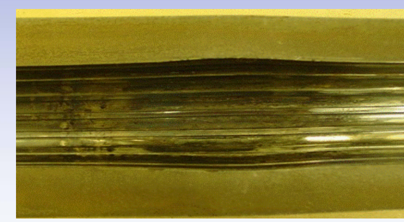
35 μs 55 μs 75 μs 100 μs



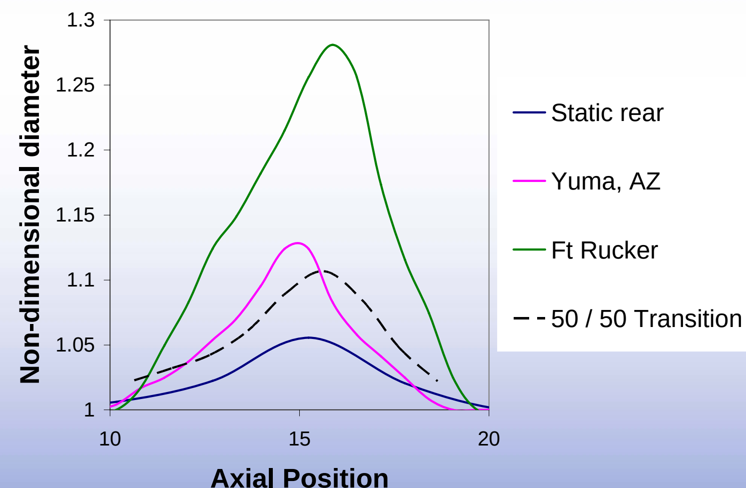


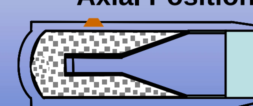


Barrel from Arizona Incident



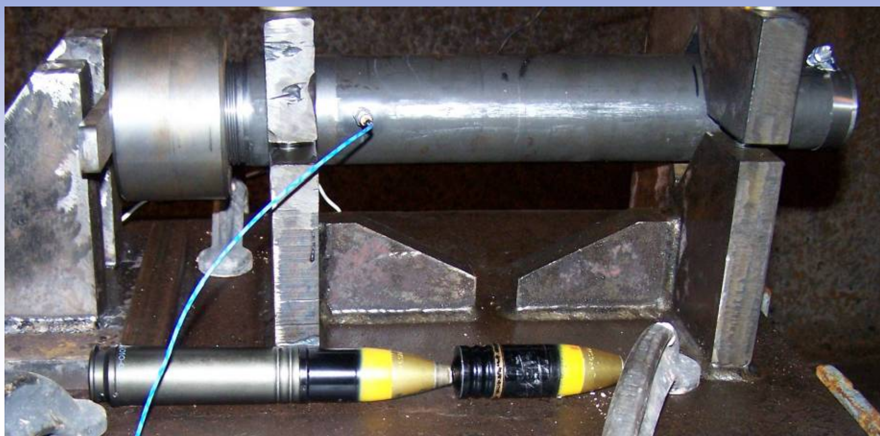
Data from Incidents, Experiment and Modeling





Signature matches an initiation at rear of warhead

Dynamic Signature Replication Bullet-on-Bullet

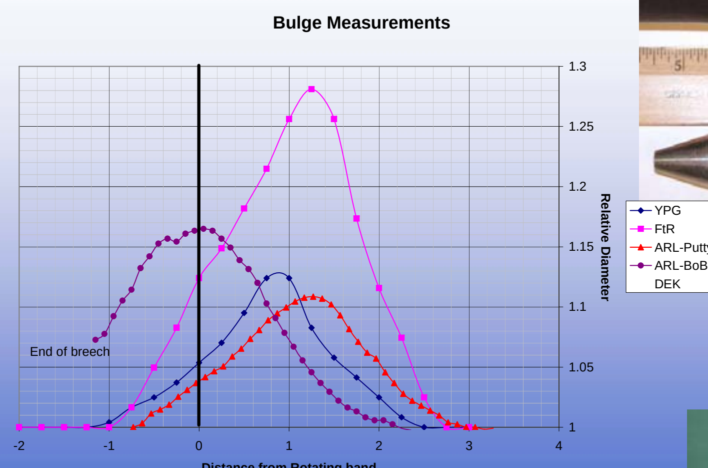


Violence and location reveal that bullet on bullet scenario not likely scenario for bulge…

Tests conducted:

- HE round → HE round (3 times)
- HE round → HE round (dummy fuze)
- HE round → TP round

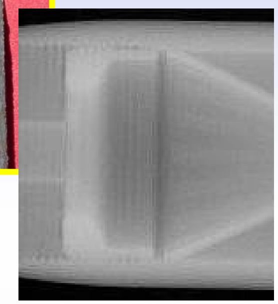
Implies rear bullet initiation



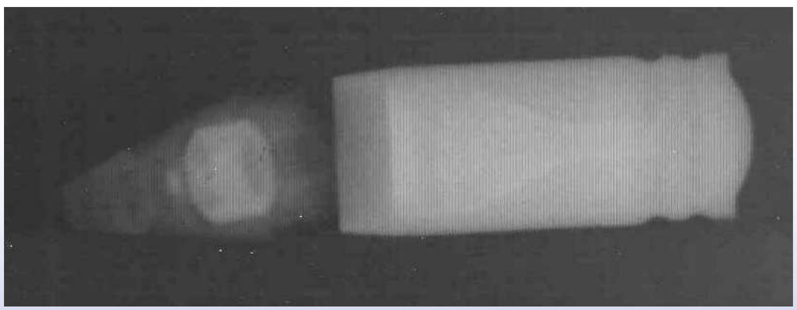
Follow-on shot with solid fuze result was an in-bore with incorrect signature

Dynamic Signature Replication Set Forward

Exuded explosive in threads



Gap between retainer and liner



Result is g-load on order of 10^3-10^5 with no reaction of projectile (Fuze ripped off body)

Liner / Retainer gaps

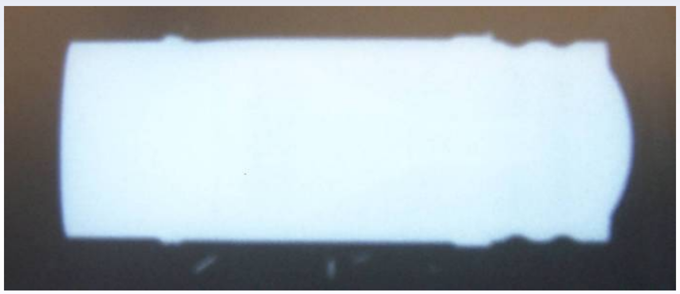
- Gap > 0.032 in (from x-ray)
- Defuzed
- 8 shots, no in-bores

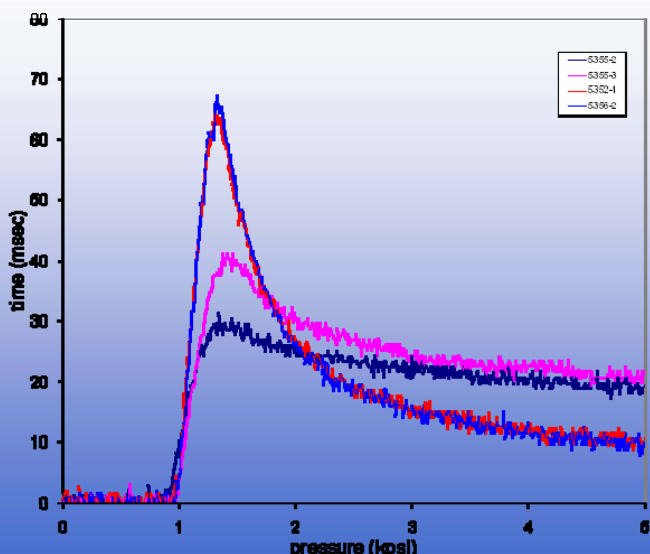
Fuzed

- No defects as determined from x-ray
- Standard, fuzed rounds
- 5 shots, no in-bores

Dynamic Signature Replication High Pressure (Body Failure)

2.00 x





Rationale

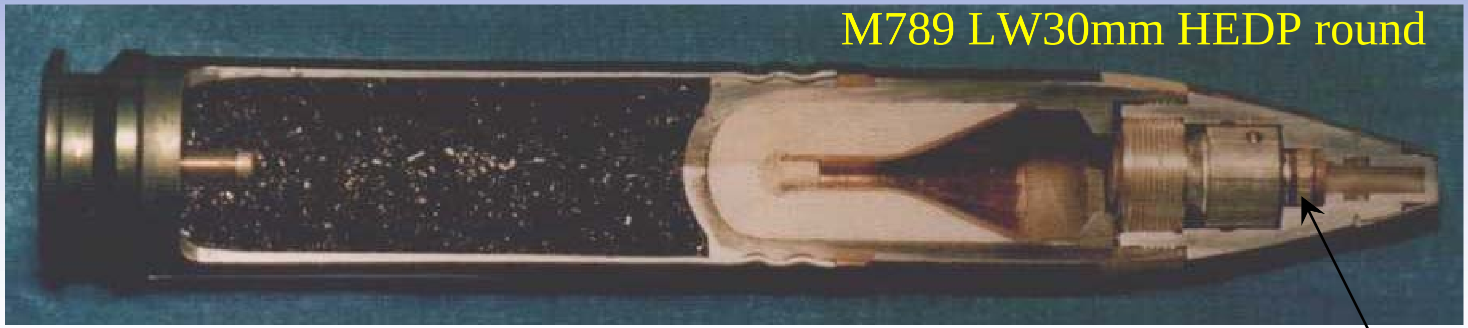
- Structural analysis found weak area in rear
- Bullet-on-bullet tests at APG:
  - 4 out of 4 shots went low order
  - Initiation from rear of projectile

Procedure

- Single projectile of increased mass
- Replace fuse with tungsten weight
- Provide data for fracture model

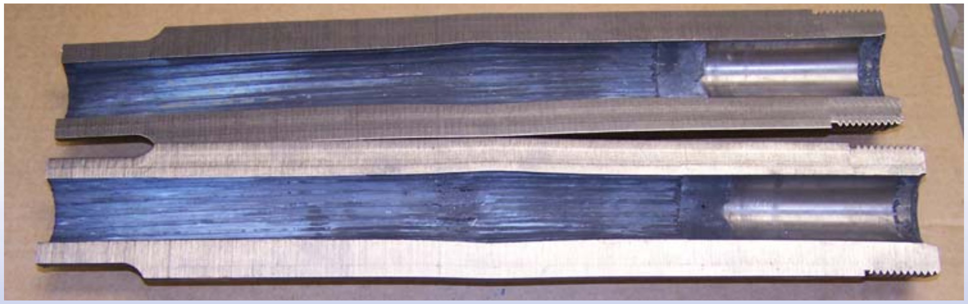
Mass taken to over double (2.25x) of projectile with subsequent increase of base pressure – NO initiation of explosive

Dynamic Signature Replication Foreign Material (aka Putty)

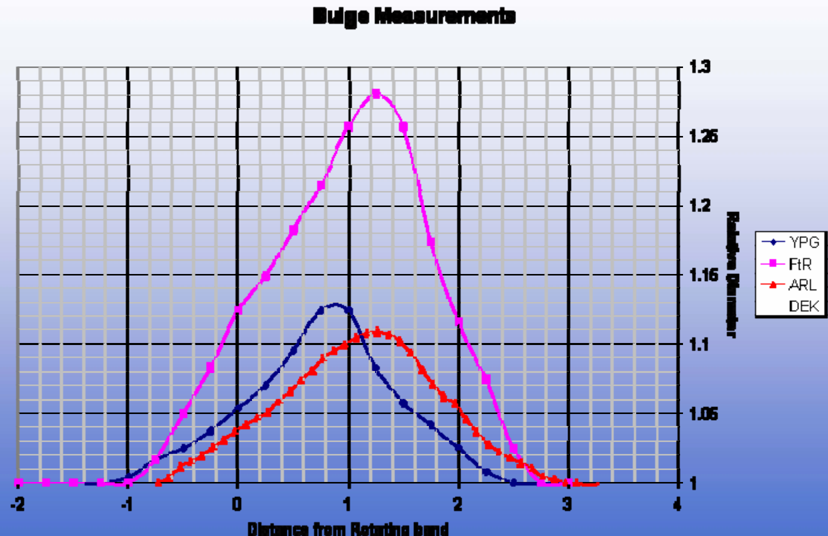


Dummy fuze replaces live fuze
(with putty to match mass)

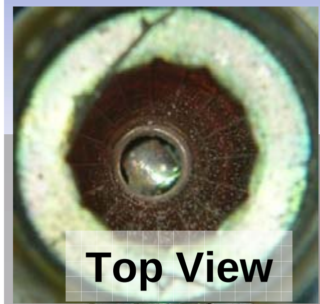
Shot 1



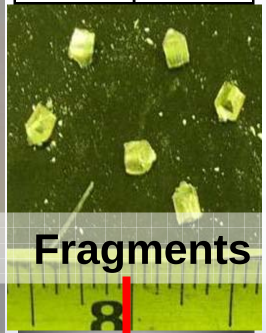
Bulged barrel centered at < 8 inches from breech

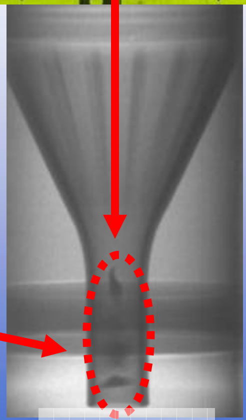


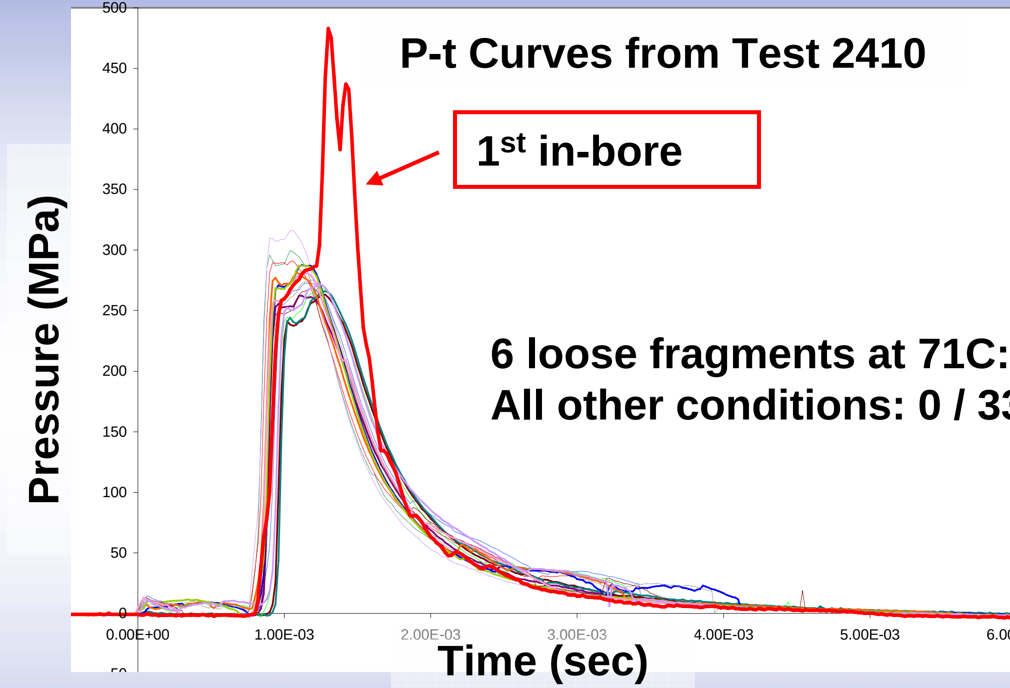
Foreign Material in Liner Cavity



Sample AA	
Fragment	Mass (mg)
1	48
2	51
3	53
4	54
5	53
6	52
Average	51.8
Total	311

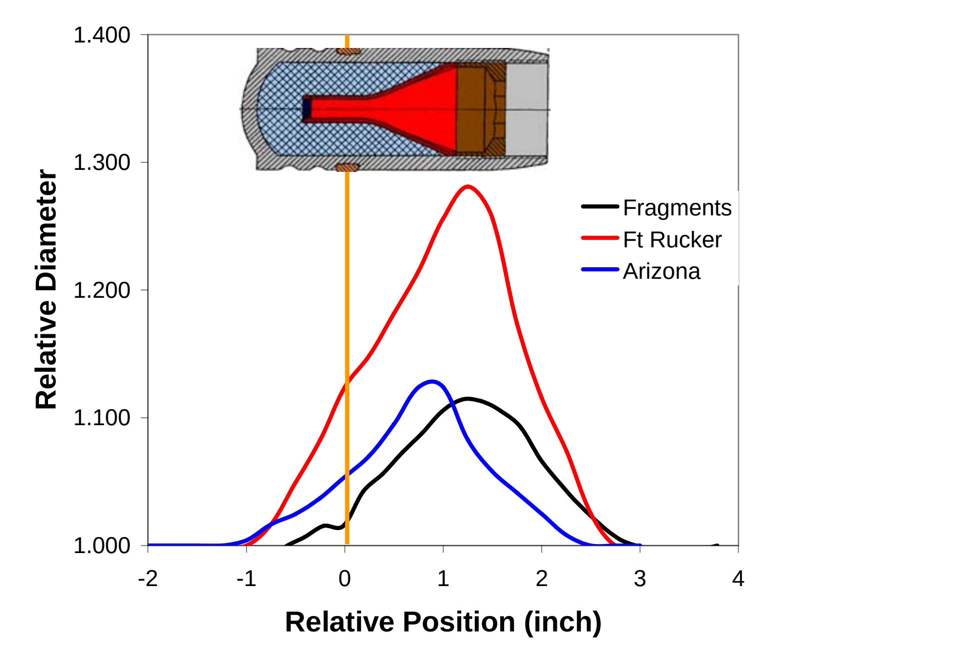






6 loose fragments at 71C: 2/2 in-bores
All other conditions: 0 / 33

Test vs. Field Incidents - Profile



Reference Line approx. 9.5" from end of barrel

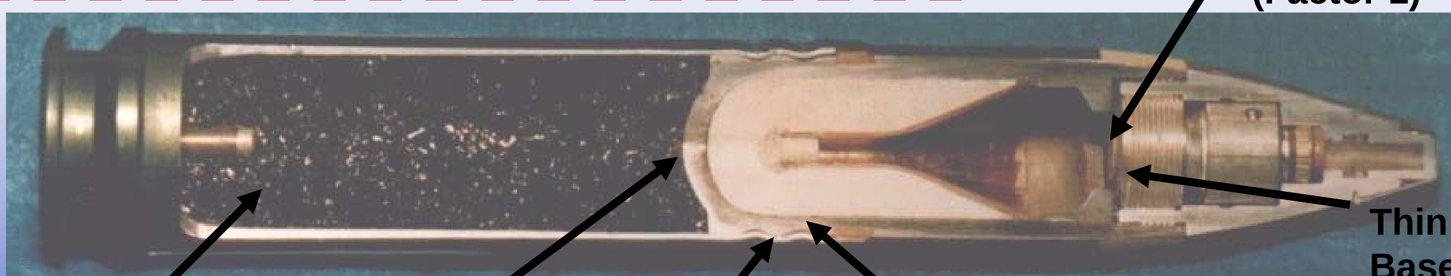
Fault Tree Probabilities for In-Bore DOE Factors

Block	Reliability	Prob. of Failure		Final Probability	Priority Ranking	
#504 Setback initiation due to debris in cavity	1	1.0005E-05	A1.11	1.0005E-05		In-bore demonstrated in Test 2410
#65 Thin sidewall body fails on setback	1	7.8400E-07	A1.12	7.8399E-07	1	Factor 4
#502 Particles embedded in HE cause HE to iniiate at setback	1	5.0000E-07	A1.15	4.9999E-07	2	Cu shaving test at High P in DOE SOW
Normal projectile ?	0.9914	9.9137E-01	A2.1	4.5107E-08	3	
#504 Setback initiation due to debris in cavity	0.9999	1.0000E-04	A2.11	1.6300E-09	4	
#1 Thin BCP flange fails on setback	1	1.1000E-09	A1.17	1.1000E-09	5	Factor 2
#307 Projectile Base deformed by propulsion gases	1	6.6700E-10	A1.9	6.6699E-10	6	Factor 3
#303 baseplug Vibrates loose	1	3.3400E-10	A1.2	3.3399E-10	7	Factor 1
#80 Cut Cartridge Case	1	1.0000E-10	A1.3	9.9998E-11	8	Factor 5
#502 Particles embedded in HE cause HE to initiate at setback	1	5.0000E-06	A2.15	8.1500E-11	9	
Improperly secured HE moves back and detonates at setback	1	2.0000E-11	A1.16	2.0000E-11	10	
#65 Thin sidewall body fails on setback	1	6.4000E-07	A2.12	1.0432E-11	11	
PBXN-5 Develops cracks in storage #51	1	1.0001E-11	C1.1	1.0001E-11	12	
Voids in explosive pellet #52	1	1.0000E-11	C1.3	1.0000E-11	13	

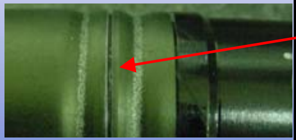
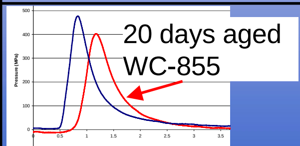
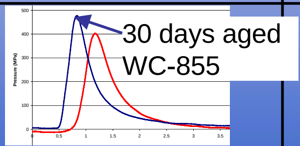
Factor 6 – Chamber Pressure G1 and G2

DOE Factor
Special Purpose Test
Redundant with a Prior Element Being Testing

In spec Ballistic Event	1.6345E-05	9.9998E-01	A1.1
#503 High pressure event	0.9227	1.63000E-05	G2
#503 Maximum pressure event	0.9985	4.55000E-08	G1

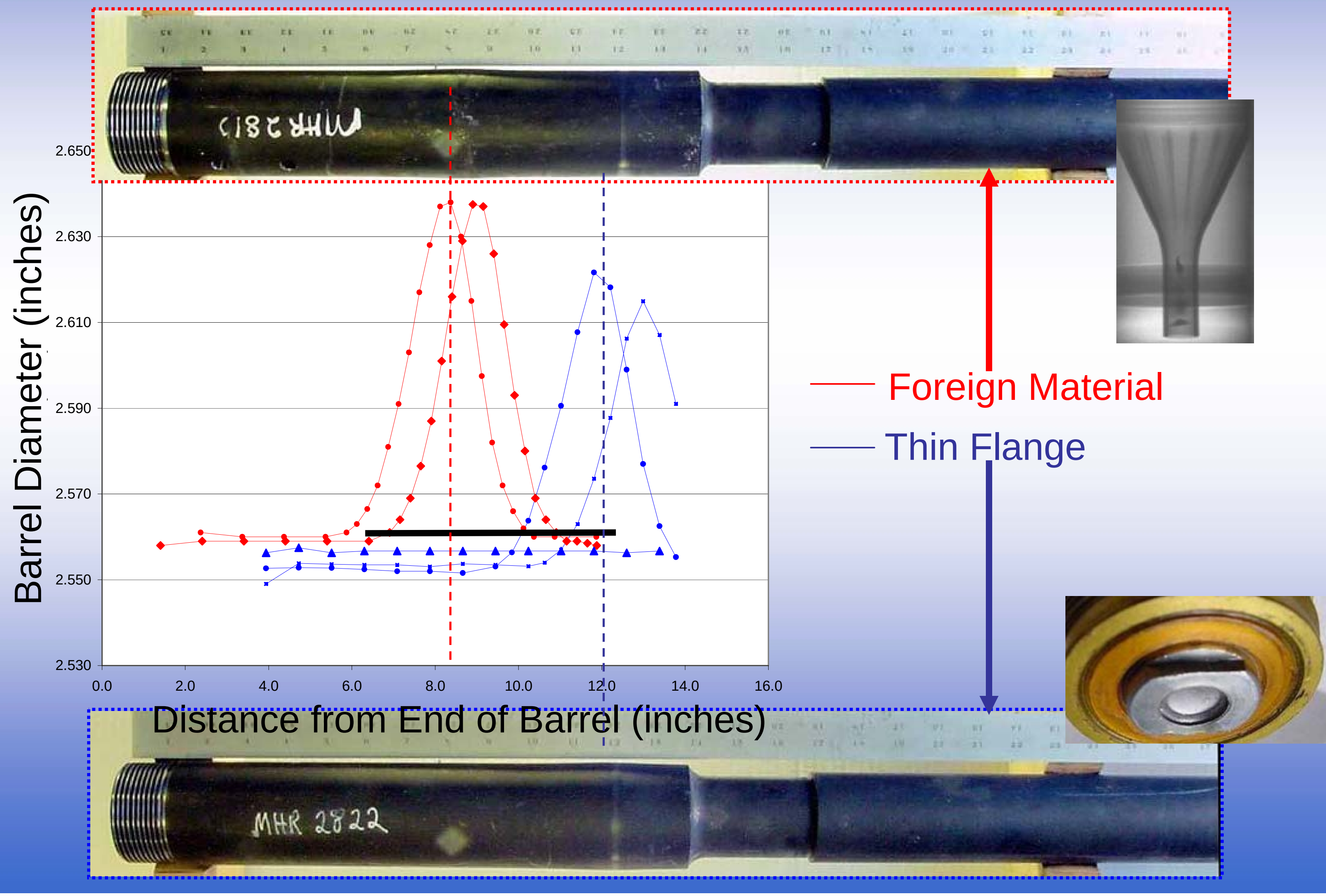


Main In-bore DOE

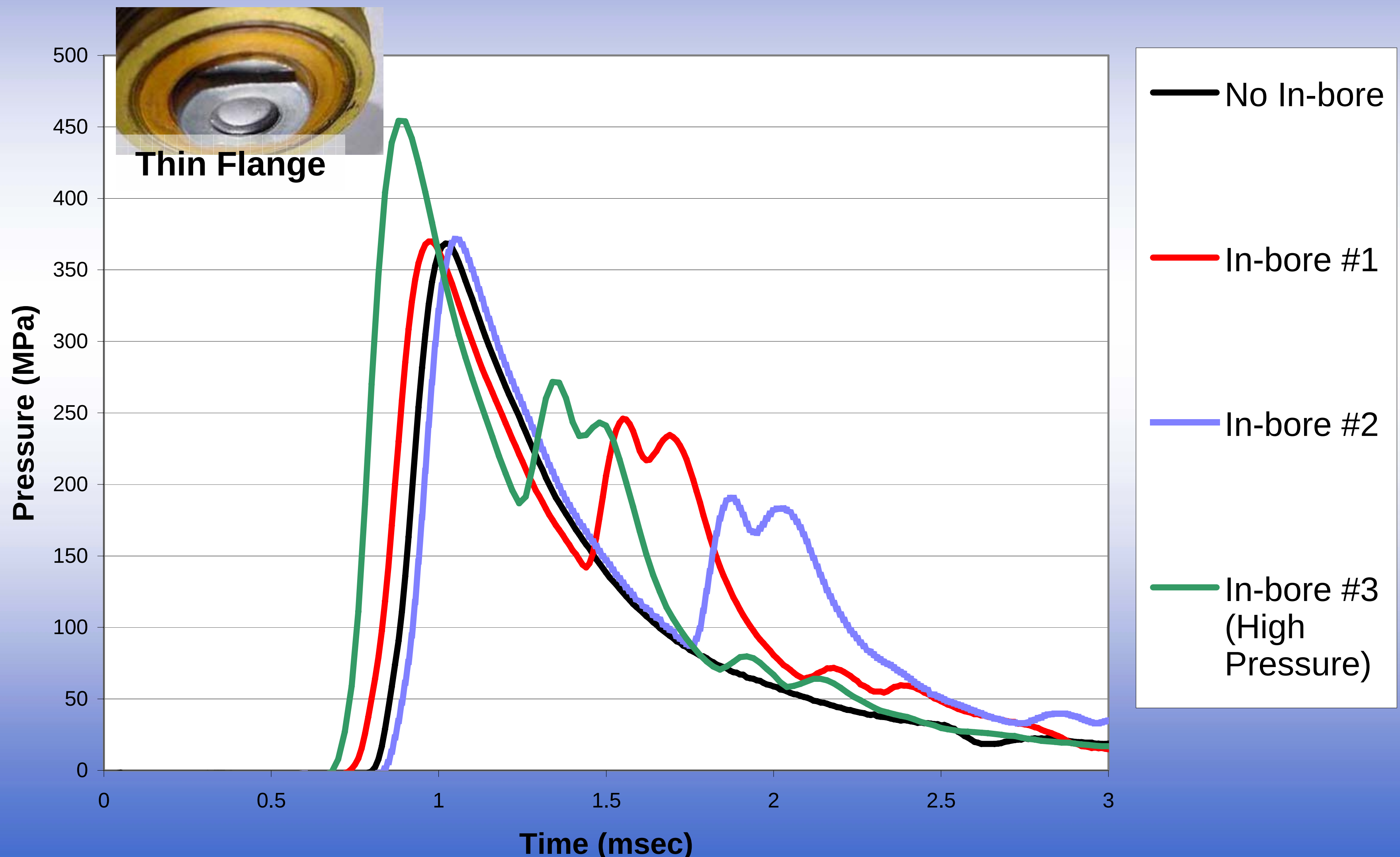
Factor	Example of "On" Factor Setting		Example of "Off" Factor Setting		Test Results	
					Shots "on"	In-bores
Loose BCP		~1/2 Thread Engagement		Full Thread Engagement	80	0
Thin BCP Flange		~ .015" Flange Thickness		~ .044" Flange Thickness	5	3
Thin Dome		~.05" Dome Thickness		~.125" Dome Thickness	80	0
Eccentric Cavity		Max Eccentricty (~.020")		Nominal Eccentricty (~.008")	80	0
Cut Cart. Case		Cut through case to proj. body		No Cut	80	0
High Pressure		~405 MPa Chamber		~480 MPa Chamber	81*	1

* 1 shot included thin BCP Flange

Test In-bore Comparisons



P-t Curves from DOE In-bores (Thin Flange)



Inbore Detonation

- Most Likely Causes
  - Foreign Material from Manufacturing Process in Liner Cavity (Replicated)
  - Thin Flange/Spitback Crimp (Replicated)
- Actions Taken to Date to Reduce/Eliminate Issue
  - –1980s Production Placed into Condition Code 'N'
    - Removed to Strategic Reserve in Kuwait Planned for Demilitarization When Stockpile has been Replenished
  - –1990+ Production
    - Thin Flange on Base Closing Plug Identified as a Critical Defect
      - **Additional Testing Added to Verify Design Margin**
      - **Double Automated Inspections Added to Manufacturing Line**
    - Affected Lots (Prior Inbore Detonations) Restricted from Use Until Screened
    - X-Ray Screening to Remove Defective Rounds Being Initiated
    - Manufacturing Process has been Modified to Eliminate Source of Foreign Material
  - –AIN & ASAM Issued to Minimize Ammo Exposure to Extreme Temperatures

Bullet on Bullet

Bullet on Bullet

A loss of propellant due to punctured case caused:

1 Increased Action Time (5 to 24 ms)
2 Decreased Range
3 Projectiles stuck beyond origin of rifling at ~15% propellant load
4 Projectiles stuck at origin of rifling or failed to debullet at 5-10% propellant load.

Field Incident

Stuck Projectile Test

Bullet on Bullet

- Most Likely Causes
  - Cartridge Cases are Punctured and Propellant is Lost
    - Efficiency Loss to a Level of 10-15% (Replicated)
- Actions Taken to Reduce/Eliminate Issue
  - ASAM #AH-64-07-ASAM-13 Issued
    - Emphasizes Use of "Auto" Mode for D Model Apache Sideloader which Minimizes Risk of Creating and Firing Punctured Cases
    - Requires Download and Inspection of Ammunition at Aircraft Regularly Scheduled Maintenance
    - Re-emphasizes the Need for Caution Uploading/Downloading the Aircraft to Avoid Punctured Cartridge Cases

Summary

- Investigation is Completed
- Final Reports are Being Written for Individual as well as Combined Efforts
- Investigation Results are Being Formulated into:
  – Design Changes
  – Manufacturing Process Changes
  – Stockpile, Manual and/or Procedural Changes, as Applicable