Evaluation of Shipping Pipes used to Transport Explosives under DOT-SP-8451

Final Report (Volume 1)
Test Report for Tasks 1 - 4 (Explosive Substances)

DOT PHMSA Contract # DTPH5616D00001, Task Order 0003
SwRI® Project 24731

Prepared by:

Troy A. Gardner, P.E., CSP (SMS)
Jared S. Teter, Ph.D. (SMS)
Jason Ford (SMS)
Derek J. Holmstead (SMS)
Michael G. MacNaughton, Ph.D., P.E. (SwRI)

Prepared for:

DOT PHMSA
1200 New Jersey Avenue SE
Washington, DC 20590

December 15, 2020

SOUTHWEST RESEARCH INSTITUTE®
6220 Culebra Road • P.O. Drawer 28510
San Antonio, Texas 78228-0510

SOUTHWEST RESEARCH INSTITUTE®
6220 CULEBRA ROAD • P.O. DRAWER 28510
SAN ANTONIO, TEXAS 78228-0510

Evaluation of Shipping Pipes used to Transport Explosives under DOT-SP-8451

Final Report (Volume 1)
Test Report for Tasks 1 - 4 (Explosive Substances)

DOT PHMSA Contract # DTPH5616D00001, Task Order 0003
SwRI® Project 24731

Prepared by:

Troy A. Gardner, P.E., CSP (SMS)
Jared S. Teter, Ph.D. (SMS)
Jason Ford (SMS)
Michael G. MacNaughton, Ph.D., P.E. (SwRI)

Prepared for:

DOT PHMSA
1200 New Jersey Avenue SE
Washington, DC 20590

Approved by:

Michael G. MacNaughton, Ph.D., P.E.
Vice President
Chemistry and Chemical Engineering Division

TABLE OF CONTENTS

TABLES

PHOTOS

1.0 OBJECTIVE

The U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) requested that Southwest Research Institute (SwRI) determine the blast-containment capacity of the U.S. DOT PHMSA Special Permit (DOT-SP) 8451 containment pipe for explosive substances centered in the containment pipe or in contact with the pipe's sidewall when intentionally initiated or when exposed to a fire.

2.0 SUMMARY AND CONCLUSIONS

Safety Management Services, Inc. (SMS) conducted testing under contract to Southwest Research Institute (SwRI) to determine the blast-containment capacity of the DOT-SP 8451 containment pipe. Testing consisted of UN Series 6 tests on the unpackaged containment pipe at SMS's test site in Tooele, Utah. Tests were witnessed by Jason Ford and performed in accordance with the United Nations (UN) Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, Sixth revised edition (2015).

Test substances included explosives such as TNT, HMX, Composition B, PETN, smokeless powder, CL-20, ANFO, and Composition A-5. The test substance that produced the most severe damage to the DOT-SP 8451 4-inch diameter containment pipe when intentionally initiated or when exposed to fire was the cyclotetramethylene-tetranitramine (HMX) test sample centered within the containment pipe and/or contacting the sidewall of the containment pipe.

The DOT-SP 8451 containment pipe can contain a centered detonation of approximately 25 grams of HMX with minimal deformation and approximately 85 grams of HMX without breaching; the containment pipe was compromised at 95 grams (pipe nipple blown off end cap). Similarly, a DOT-SP 8451 containment pipe using a 7-inch pipe nipple (nominally a 50% reduction in free volume) can contain a centered detonation of approximately 25 grams of HMX with minimal deformation; the containment pipe was compromised using a 6-inch pipe nipple.

> *NOTE: These capacities are based on a single trial; additional trials can be performed to increase the level of confidence.*

3.0 BACKGROUND

Eight test samples were to be selected for the initial DOT-SP 8451 testing; test samples were recommended by SMS based upon the heats of detonation and combustion, product availability, and variety amongst the allowable eight samples. The following table lists the test samples approved by U.S. DOT PHMSA.

Table 1: Test Samples Selected for DOT-SP 8451 Containment Pipe Testing

Sample ID	Sample Name
1	TNT
2	HMX
3	Composition B
4	PETN
5	Smokeless Powder
6	CL-20
7	ANFO
8	Composition A-5

4.0 DESCRIPTION OF DOT-SP 8451 TEST SAMPLES

4.1 DOT-SP 8451 Containment Pipe

The U.S. DOT Pipeline and Hazardous Materials Safety Administration (PHMSA) Special Permit (DOT-SP) 8451 containment pipe is a 4-inch × 14-inch Schedule 80 seamless steel pipe nipple closed at both ends with 3,000-psi forged steel end caps per ASTM 105. The pipe threads are cut so that the end caps can be screwed on a minimum of 5 threads by hand.

Photo 1: DOT-SP 8451 Containment Pipe

4.2 TNT

The sample of trinitrotoluene (TNT) was supplied by Accurate Energetic Systems, LLC of McEwen, Tennessee and was identified as P/N ET-1000, “TNT, MIL-SPEC”. The sample consisted of small flakes and is shown in the following photo.

Photo 2: Trinitrotoluene (TNT) Sample

4.3 HMX

The sample of cyclotetramethylene-tetranitramine (HMX), also known as Octogen, was supplied by Accurate Energetic Systems, LLC of McEwen, Tennessee and was identified as P/N EH-1003C, "HMX, GRADE B, CLASS 3, COMMERCIAL". The sample is a fine, white crystalline powder and is shown in the following photo.

Photo 3: Cyclotetramethylene-tetranitramine (HMX) Sample

4.4 Composition B

The sample of Composition B (Comp B) was supplied by Accurate Energetic Systems, LLC of McEwen, Tennessee and was identified as P/N ER-5201C, “COMPOSITION B, COMMERCIAL”. The nominal composition of the product was 60/40 mixture of 1,3,5-trinitro-1,3,5-triazine (RDX) to TNT. The sample consisted of small thin, flat pieces of the composition and is shown in the following photo.

Photo 4: Composition B Sample

4.5 PETN

The sample of pentaerythritol tetranitrate (PETN) was supplied by Accurate Energetic Systems, LLC of McEwen, Tennessee and was identified as P/N EP-1003, “PETN, CLASS III, MIL-P-387”. The sample is a fine, white crystalline powder and is shown in the following photo.

Photo 5: Pentaerythritol Tetranitrate (PETN) Sample

4.6 Smokeless Powder

The Alliant Powder Bullseye® smokeless pistol powder was purchased locally from a sporting goods store. The sample consists of very small flakes of smokeless gun powder and is shown in the following photo.

Photo 6: Alliant Powder Bullseye® Smokeless Pistol Powder

4.7 CL-20

The sample of hexanitrohexaazaisowurtzitane (CL-20) was supplied by Northrop Grumman Innovation Systems of Promontory, Utah. The particle size of the sample was 1 - 3 µm.

4.8 ANFO

The sample of ammonium nitrate/fuel oil (ANFO) was manufactured by DYNO Nobel and supplied by Accurate Energetic Systems, LLC of McEwen, Tennessee and was identified as P/N EZ-ANFO, "ANFO, BAGGED".

4.9 Composition A-5

The sample of Composition A-5 (Comp A-5) was supplied by Accurate Energetic Systems, LLC of McEwen, Tennessee and was identified as P/N ER-5150, "COMPOSITION A-5, MIL-SPEC". The sample is shown in the following photo.

Photo 7: Composition A-5 Sample

5.0 IDENTIFYING THE WORST-CASE TEST SUBSTANCE BY EFFECTS

5.1 Unpackaged UN Series 6 (d) Unconfined Package Test

5.1.1 Test Description

This test is performed to determine which substance produces worst-case blast effects when intentionally initiated within a DOT-SP 8451 containment pipe, as evidenced by the greatest pipe deformation.

A pre-determined quantity of the test substance is poured into a grounded, conductive plastic bag. A detonator of sufficient strength to initiate the substance is inserted centrally into the top of the test substance; the bag is closed and detonator secured. The assembly is positioned within the containment pipe (surrounded by sufficient bubble wrap and centered within the containment pipe or taped to the pipe's sidewall in the middle of the pipe). The containment

pipe is closed with end caps that are screwed on a minimum of five threads by hand and then tightened with a wrench.

The unpackaged pipe is placed upon the ground and the circumfrence measured before and after the test at the top, middle, and bottom of the containment pipe. The substance producing the greatest pipe deformation is designated as the worst-case test substance when intentionally initiated.

5.1.2 Test Configuration

A detonator containing 0.8 grams of PETN was utilized for each of the trials. The igniter wires were passed outside of the containment pipe using an end cap modified with two grub-style screws, one electrically insulated from the other (similar to those utilized in the UN MTC, sixth revised edition, Appendix 7, HSL Flash Composition test).

Photo 8: Shunted Bulkhead Connectors and Detonator (typical)

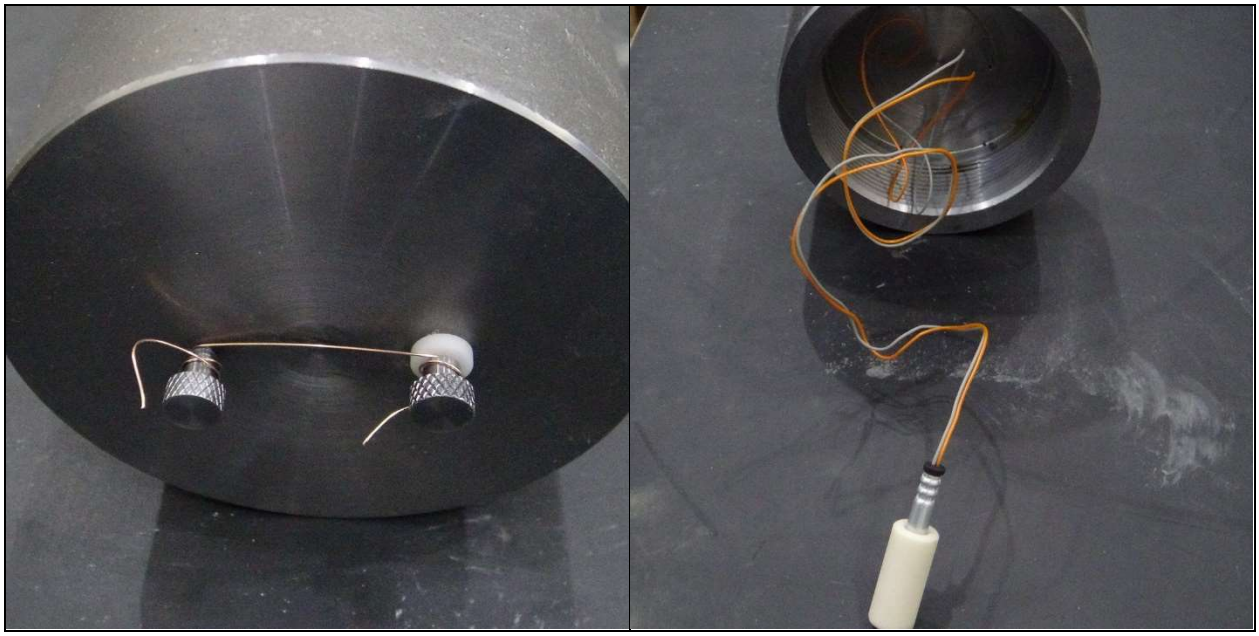


Photo 9: Detonator and Test Substance (typical)

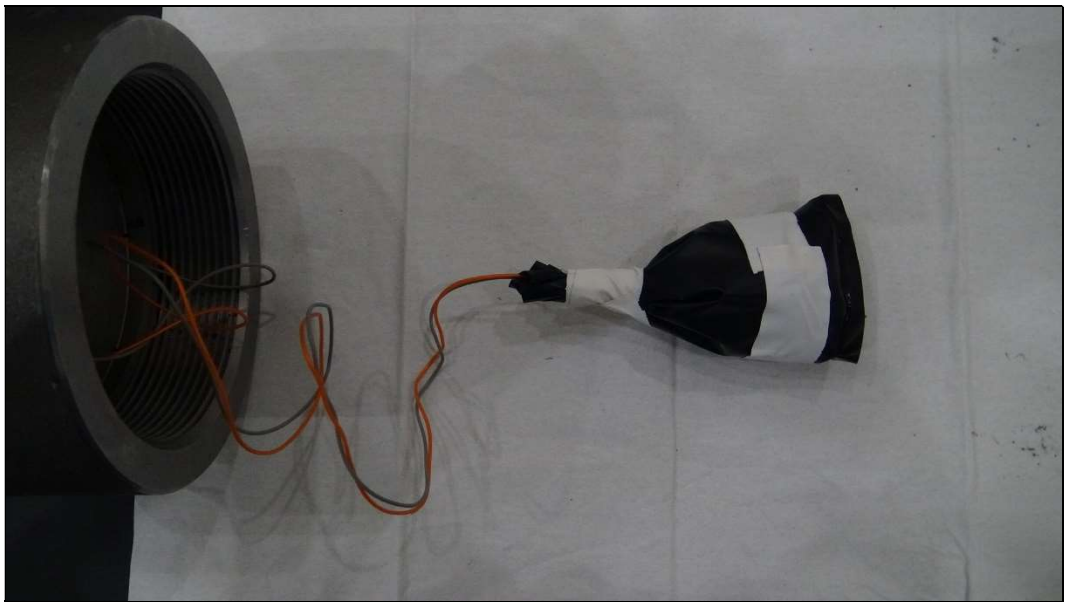


Photo 10: Unconfined Package Test Setup - Substance Centered in Pipe using Bubble Wrap (typical)

Photo 11: Unconfined Package Test Setup - Substance Contacting Sidewall (typical)

Photo 12: Unconfined Package Test Setup (typical)

The circumference before the test at the top, middle, and bottom measurement locations was 36.4 cm for each of the containment pipes.

5.1.3 Test Results - Substance Centered in Containment Pipe

Initiation of the detonator resulted in explosion of each substance centered in the DOT-SP 8451 4-inch diameter containment pipe, as summarized in the following table.

Table 2: Unconfined Package Test Results (Substance in Center)

Item	Substance	Mass (g)	Top* (cm)	Middle (cm)	Bottom (cm)	Comments
1	TNT	50	36.4	36.4	36.4	No visible damage.
2	**HMX**	**50**	**36.4**	**38.1**	**36.4**	**Center of pipe visibly bulged.**
3	Comp B	50	36.4	36.4	36.4	No visible damage.
4	PETN	50	36.4	38.0	36.4	Center of pipe visibly bulged.
5	Bullseye®	50	36.4	36.4	36.4	No visible damage.
6	CL-20	50	36.4	37.5	36.4	Slight bulge in center of pipe.
7	ANFO	50	36.4	36.4	36.4	No visible damage.
8	Comp A-5	50	36.4	38.0	36.4	Center of pipe visibly bulged.

*Post-Test Dimensions

The test results are shown in the following photos.

Photo 13: Unconfined Package Test Results (Substance in Center) - TNT

Photo 14: Unconfined Package Test Results (Substance in Center) - HMX

Photo 15: Unconfined Package Test Results (Substance in Center) - Comp B

Photo 16: Unconfined Package Test Results (Substance in Center) - PETN

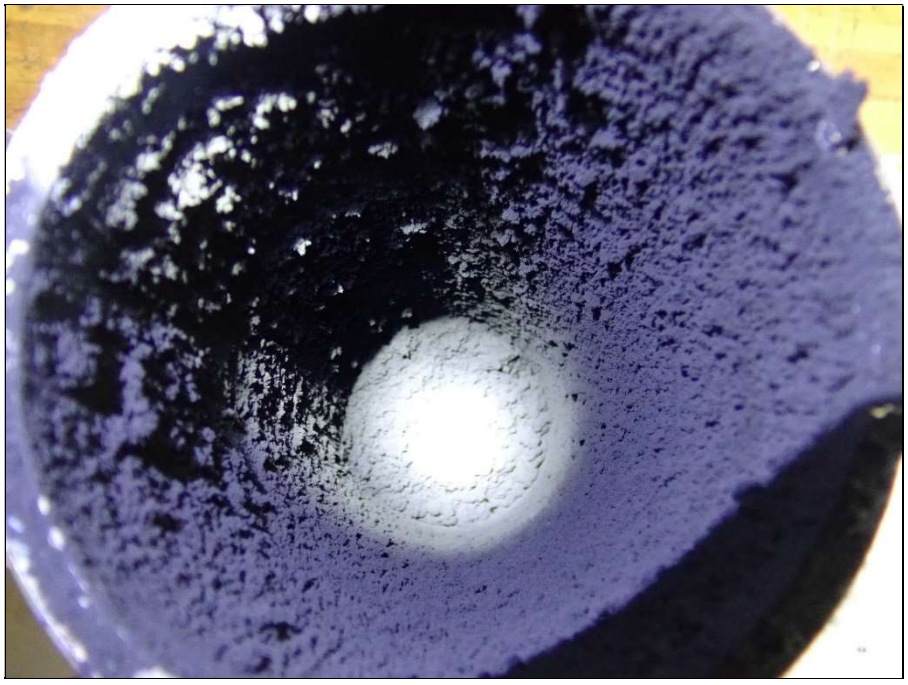
Photo 17: Unconfined Package Test Results (Substance in Center) - Bullseye®

Photo 18: Unconfined Package Test Results (Substance in Center) - CL-20

Photo 19: Unconfined Package Test Results (Substance in Center) - ANFO

Photo 20: Unconfined Package Test Results (Substance in Center) - Comp A-5

Photo 21: Unconfined Package Test Results (Substance in Center) - Typical Product and Bubble Wrap Residue



5.1.4 Test Results - Substance Contacting Sidewall of Containment Pipe

Initiation of the detonator resulted in explosion of each substance contacting the sidewall of the DOT-SP 8451 4-inch diameter containment pipe, as summarized in the following table.

Table 3: Unconfined Package Test Results (Substance Contacting Sidewall)

Item	Substance	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Comments
1	TNT	50	36.4	36.4	36.4	No visible damage.
2	**HMX**	**50**	**36.4**	**39.4**	**36.4**	**Perforated sidewall (8 x 1 cm).**
3	Comp B	50	36.4	36.4	36.4	No visible damage.
4	PETN	50	36.4	38.7	36.4	Large localized bulge in center.
5	Bullseye®	50	36.4	37.3	36.4	Slight localized bulge in center.
6	CL-20	50	36.4	37.8	36.4	Localized bulge in pipe center.
7	ANFO	50	36.4	36.4	36.4	No visible damage.
8	Comp A-5	50	36.4	39.3	36.4	Large localized bulge in center.

The test results are shown in the following photos.

Photo 22: Unconfined Package Test Results (Substance Contacting Sidewall) - TNT

Photo 23: Unconfined Package Test Results (Substance Contacting Sidewall) - HMX

Photo 24: Unconfined Package Test Results (Substance Contacting Sidewall) - Comp B

Photo 25: Unconfined Package Test Results (Substance Contacting Sidewall) - PETN

Photo 26: Unconfined Package Test Results (Substance Contacting Sidewall) - Bullseye®

Photo 27: Unconfined Package Test Results (Substance Contacting Sidewall) - CL-20

Photo 28: Unconfined Package Test Results (Substance Contacting Sidewall) - ANFO

Photo 29: Unconfined Package Test Results (Substance Contacting Sidewall) - Comp A-5

5.1.5 Conclusions

Based on the unpackaged UN Series 6 (d) Unconfined package test results, the most severe damage to the DOT-SP 8451 4-inch diameter containment pipe was from the HMX test sample when centered within the containment pipe or when contacting the sidewall of the containment pipe, followed next by Composition A-5 and then PETN.

5.2 Unpackaged UN Series 6 (c) External Fire (Bonfire) Test

5.2.1 Test Description

This test is performed to determine which substance produces worst-case blast effects when subjected to a bonfire in a DOT-SP 8451 containment pipe, as evidenced by the greatest pipe deformation.

A pre-determined quantity of the test substance is poured into a grounded, conductive plastic bag. The bag is closed and positioned within the containment pipe (surrounded by sufficient bubble wrap and centered within the containment pipe or taped to the pipe's sidewall in the middle of the pipe). The containment pipe is closed with end caps that are screwed on a minimum of five threads by hand and then tightened with a wrench.

The unpackaged pipe is placed on a non-combustible surface (steel grate) above a lattice of dried wood wetted with kerosene or diesel fuel; the pipes are secured to the steel grate. Sufficient wood is used to provide a 30-minute fire. Three witness screen frames are placed 4 meters from the edge of the stack as visible distance markers.

The circumfrence of the containment pipe is measured before and after the test at the top, middle, and bottom of the containment pipe. The substance producing the greatest pipe deformation is designated as the worst-case test substance when in a bonfire.

5.2.2 Test Configuration

The test configuration is similar to that of the unpackaged UN Series 6 (d) Unconfined package test, except that the modified end caps and detonators were omitted. The environmental conditions at time of External Fire Test 1 were 3.6 m/s wind, 12°C, 39% relative humidity and 1.3 m/s wind, 14°C, 29% relative humidity for External Fire Test 2.

Wire ties were utilized to secure the containment pipes to the steel grating to keep containers from rolling out of the fire (due to the force of gravity on an uneven surface created during test as pallet fuel is consumed and steel grate deforms), as allowed for in the UN Series 6 (c) test specification. It is noted that these wire ties do not affect the test results as the unpackaged UN Series 6 (d) demonstrated that there was no noticeable movement from reaction of the within the container, even when the product was initiated in contact with the sidewalls of the containment pipe; the wire ties would be expected to fail under application of any substanial force.

Photo 30: External Fire Test 1 Setup (Substance in Center)

Photo 31: External Fire Test 2 Setup (Substance Contacting Sidewall)

5.2.3 Test Results - Substance Centered in Containment Pipe

The test results for each substance centered in the DOT-SP 8451 4-inch diameter containment pipe in a bonfire are summarized in the following table. All reactions were fully contained within the containment pipes.

Table 4: External Fire Test Results (Substance in Center)

Item	Substance	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Comments
1	TNT	50	36.4	36.4	36.4	No visible damage.
2	HMX	50	36.4	36.4	36.4	No visible damage.
3	Comp B	50	36.4	36.4	36.4	No visible damage.
4	PETN	50	36.4	36.4	36.4	No visible damage.
5	Bullseye®	50	36.4	36.4	36.4	No visible damage.
6	CL-20	50	36.4	36.4	36.4	No visible damage.
7	ANFO	50	36.4	36.4	36.4	No visible damage.
8	Comp A-5	50	36.4	36.4	36.4	No visible damage.

The test results are shown in the following photos.

Photo 32: External Fire Test Results (Substance in Center) - TNT

Photo 33: External Fire Test Results (Substance in Center) - HMX

Photo 34: External Fire Test Results (Substance in Center) - Comp B

Photo 35: External Fire Test Results (Substance in Center) - PETN

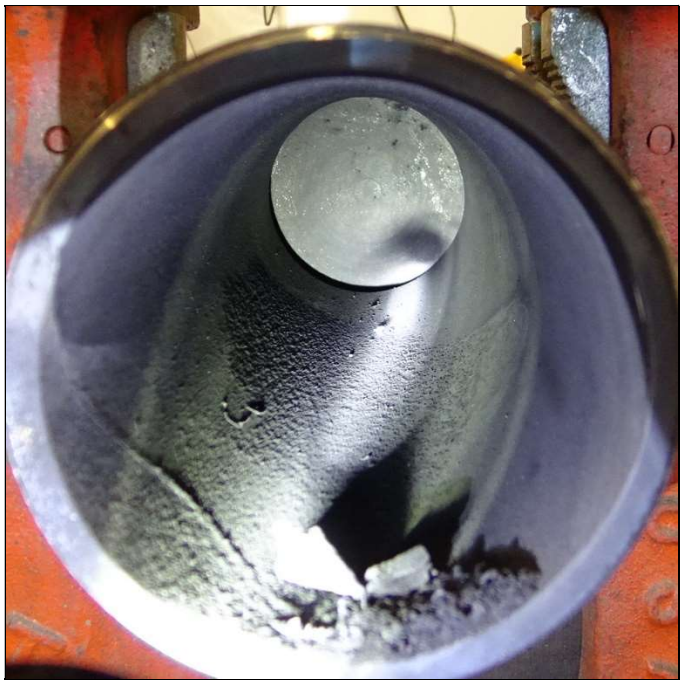
Photo 36: External Fire Test Results (Substance in Center) - Bullseye®

Photo 37: External Fire Test Results (Substance in Center) - CL-20

Photo 38: External Fire Test Results (Substance in Center) - ANFO

Photo 39: External Fire Test Results (Substance in Center) - Comp A-5

Photo 40: External Fire Test Results (Substance in Center) - Typical Product and Bubble Wrap Residue



5.2.4 Test Results - Substance Contacting Sidewall of Containment Pipe

The test results for each substance contacting the sidewall of the DOT-SP 8451 4-inch diameter containment pipe in a bonfire are summarized in the following table.

Table 5: External Fire Test Results (Substance Contacting Sidewall)

Item	Substance	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Comments
1	TNT	50	36.4	36.4	36.4	No visible damage.
2	HMX	50	36.4	36.4	36.4	No visible damage.
3	Comp B	50	36.4	36.4	36.4	No visible damage.
4	PETN	50	36.4	36.4	36.4	No visible damage.
5	Bullseye®	50	36.4	36.4	36.4	No visible damage.
6	CL-20	50	36.4	36.4	36.4	No visible damage.
7	ANFO	50	36.4	36.4	36.4	No visible damage.
8	Comp A-5	50	36.4	36.4	36.4	No visible damage.

The test results are shown in the following photos.

Photo 41: External Fire Test Results (Substance Contacting Sidewall)

5.2.5 Conclusions

Based on the unpackaged UN Series 6 (c) External fire (bonfire) test results, all test samples did not appear to damage the DOT-SP 8451 4-inch diameter containment pipe when centered within the containment pipe or when contacting the sidewall of the containment pipe.

5.3 Identification of the Worst-Case Test Substance by Effects

Based on the unpackaged UN Series 6 (d) Unconfined package and 6 (c) External fire (bonfire) test results, the most severe damage to the DOT-SP 8451 4-inch diameter containment pipe was from the HMX test sample when the substance was intentionally initiated or subjected to a bonfire when centered within the containment pipe or when contacting the sidewall of the containment pipe. Therefore, the HMX test sample is designated as the worst-case test substance.

5.4 DOT-SP 8451 Containment Capacity for the Worst-Case Substance

5.4.1 Test Description

Same as that of the unpackaged UN Series 6 (d) Unconfined package and UN Series 6 (c) External fire tests.

5.4.2 Test Configuration

Same as that of the unpackaged UN Series 6 (d) Unconfined package and UN Series 6 (c) External fire tests with the exception that only HMX, the worst-case substance, was tested with

each pipe containing between 25 - 95 grams in increments of 10 grams. The environmental conditions at time of External Fire Test 3 were 0.9 m/s wind, 16°C, 27% relative humidity

Photo 42: External Fire Test 3 Setup (Substance in Center)

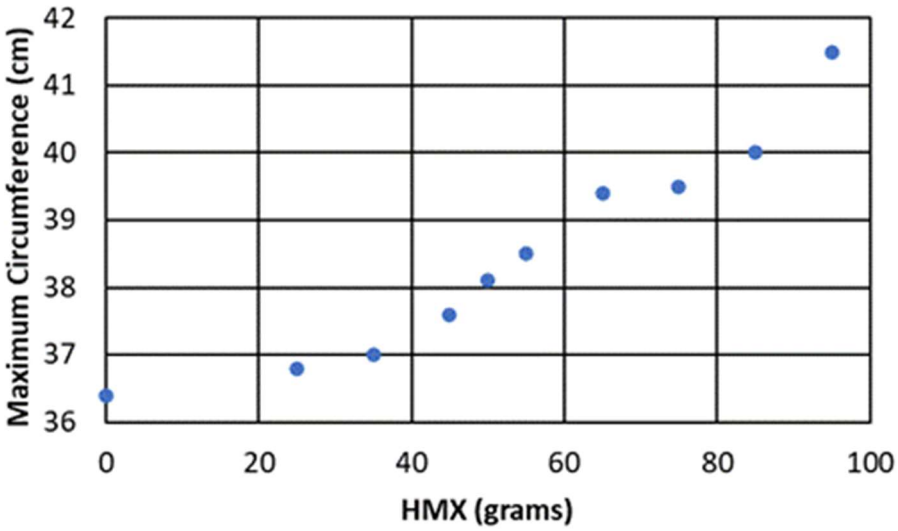
5.4.3 Unconfined Package Test Results for HMX (Worst-Case Test Substance)

The test results for HMX, the worst-case test substance, centered in the DOT-SP 8451 4-inch diameter containment pipe in a bonfire is summarized in the following table. A second 95-gram trial was performed for verification and resulted in the same result.

Table 6: Unconfined Package Test Results for HMX (Substance in Center)

Item	Substance	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Comments
1	HMX	25	36.4	36.8	36.4	Very small bulge in center.
2	HMX	35	36.4	37.0	36.4	Center of pipe slightly bulged.
3	HMX	45	36.4	37.6	36.4	Center of pipe slightly bulged.
4	HMX	55	36.4	38.5	36.4	Evident bulge in center.
5	HMX	65	36.4	39.4	36.4	Very evident bulge in center.
6	HMX	75	36.4	39.5	36.4	Center of pipe visibly bulged.
7	HMX	85	36.4	40.0	36.4	Center of pipe visibly bulged.
8	HMX	95	36.4	41.5	36.4	Large bulge in center of pipe; pipe nipple blown off end cap.
9	HMX	95	36.4	41.5	36.4	Large bulge in center of pipe; pipe nipple blown off end cap.

The change in containment pipe circumference is shown in the following plot.



The test results are shown in the following photos.

Photo 43: Unconfined Package Test Results - 25 grams of HMX in Center

Photo 44: Unconfined Package Test Results - 35 grams of HMX in Center

Photo 45: Unconfined Package Test Results - 45 grams of HMX in Center

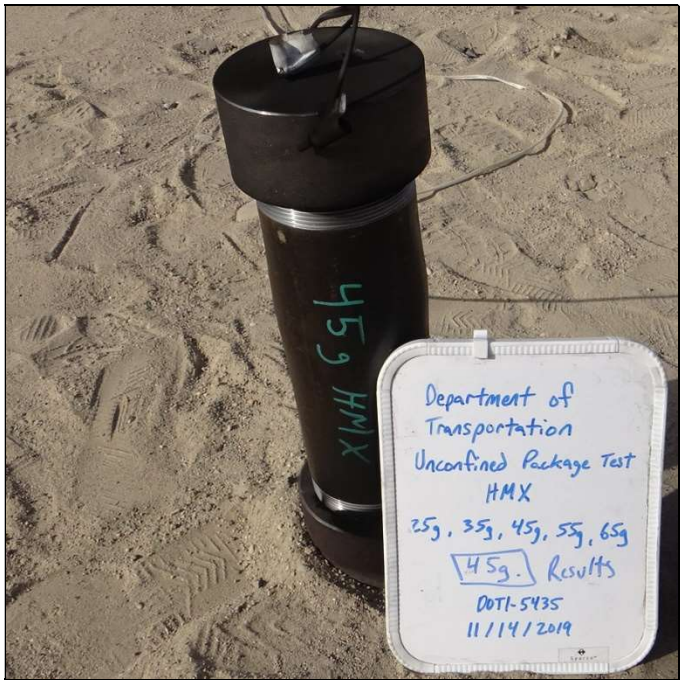


Photo 46: Unconfined Package Test Results - 55 grams of HMX in Center

Photo 47: Unconfined Package Test Results - 65 grams of HMX in Center

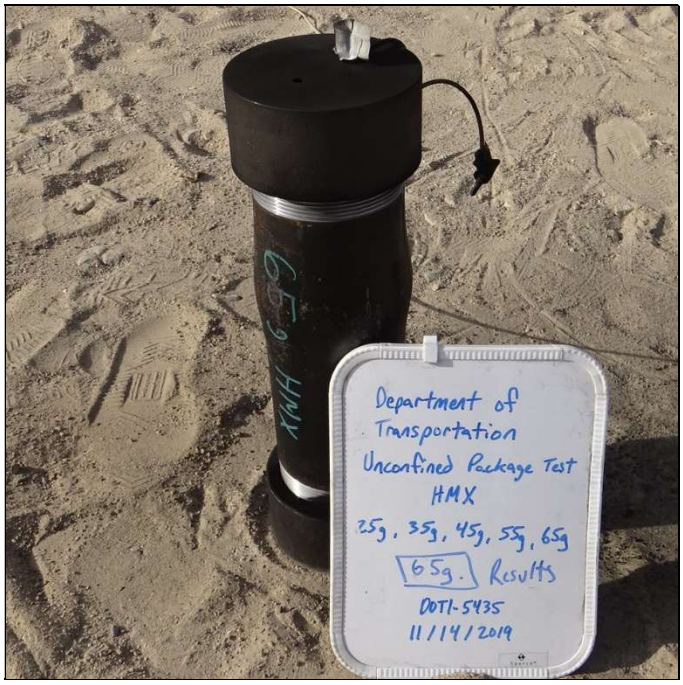


Photo 48: Unconfined Package Test Results - 75 & 85 grams of HMX in Center

Photo 49: Unconfined Package Test Results - 95 grams of HMX in Center (two trials)

5.4.4 External Fire Test Results for HMX (Worst-Case Test Substance)

The test results for HMX, the worst-case test substance, centered in the DOT-SP 8451 4-inch diameter containment pipe in a bonfire is summarized in the following table.

Table 7: External Fire Test Results for HMX (Substance in Center)

Item	Substance	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Comments
1	HMX	25	36.4	36.4	36.4	No visible damage.
2	HMX	35	36.4	36.4	36.4	No visible damage.
3	HMX	45	36.4	36.4	36.4	No visible damage.
4	HMX	55	36.4	36.4	36.4	No visible damage.
5	HMX	65	36.4	36.4	36.4	No visible damage.
6	HMX	75	36.4	36.4	36.4	No visible damage.
7	HMX	85	36.4	36.4	36.4	No visible damage.
8	HMX	95	36.4	36.4	36.4	No visible damage.

The test results are shown in the following photo.

Photo 50: External Fire Test Results - 25 - 95 grams of HMX in Center

5.4.5 Conclusions

Based on the test results, the DOT-SP 8451 containment pipe was able to contain a centered detonation of approximately 25 grams of HMX with minimal deformation and approximately 85 grams of HMX without breaching; the containment pipe was compromised at 95 grams (pipe nipple blown off end cap).

NOTE: These capacities are based on a single trial; additional trials can be performed to increase the level of confidence.

5.5 DOT-SP 8451 Void Space Study for the Worst-Case Substance

5.5.1 Test Description

Same as that of the unpackaged UN Series 6 (d) Unconfined package and UN Series 6 (c) External fire tests.

5.5.2 Test Configuration

Same as that of the unpackaged UN Series 6 (d) Unconfined package and UN Series 6 (c) External fire tests with the exception that only HMX, the worst-case substance, was tested with each pipe containing 25 grams in lengths of 6 to 13 inches in 1-inch increments. The environmental conditions at time of External Fire Test 4 were 4.0 m/s wind, 1°C, 72% relative humidity.

Photo 51: DOT-SP 8451 Shipping Pipes in Decreasing Lengths (13 to 6 inches in 1-inch increments)

Photo 52: External Fire Test 4 Setup for Decreasing Lengths (13 to 6 inches in 1-inch increments)

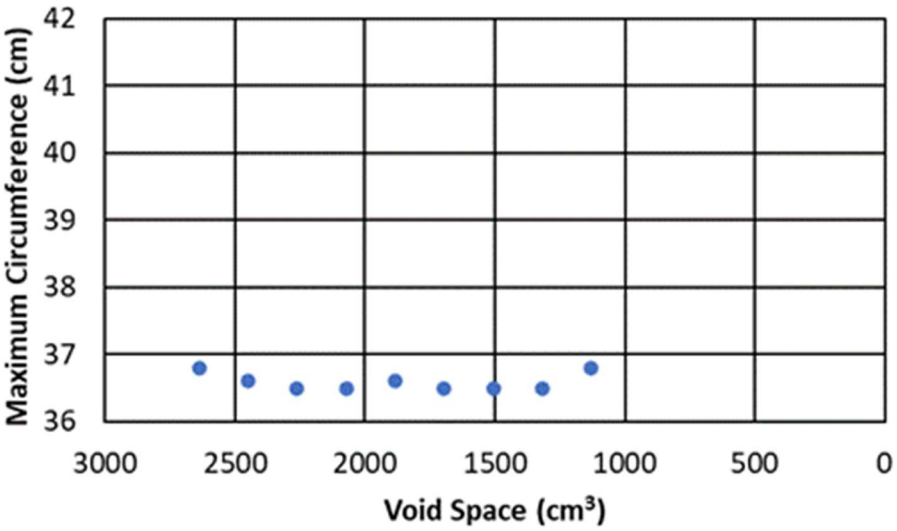
5.5.3 Unconfined Package Test Results for HMX (Worst-Case Test Substance)

The test results for HMX, the worst-case test substance, centered in the DOT-SP 8451 4-inch diameter containment pipe in a bonfire is summarized in the following table. A second 95-gram trial was performed for verification and resulted in the same result.

Table 8: Unconfined Package Test Results for HMX (Substance in Center of Decreasing Length Pipe)

Item	Pipe Length (in)	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Comments
1	13	25	36.3	36.6	36.3	Very small bulge in center.
2	12	25	36.3	36.5	36.3	Very small bulge in center.
3	11	25	36.3	36.5	36.3	Very small bulge in center.
4	10	25	36.3	36.6	36.3	Very small bulge in center.
5	9	25	36.3	36.5	36.3	Very small bulge in center.
6	8	25	36.3	36.5	36.3	Very small bulge in center.
7	7	25	36.3	36.5	36.3	Very small bulge in center.
8	6	25	36.7	36.8	36.7	Very small bulge in center.

The change in containment pipe circumference with reduction in void space for 25 grams of HMX is shown in the following plot.



The test results are shown in the following photos.

Photo 53: Unconfined Package Test Results - 25 grams of HMX in Center of 13-inch Long Pipe

Photo 54: Unconfined Package Test Results - 25 grams of HMX in Center of 12-inch Long Pipe

Photo 55: Unconfined Package Test Results - 25 grams of HMX in Center of 11-inch Long Pipe

Photo 56: Unconfined Package Test Results - 25 grams of HMX in Center of 10-inch Long Pipe

Photo 57: Unconfined Package Test Results - 25 grams of HMX in Center of 9-inch Long Pipe

Photo 58: Unconfined Package Test Results - 25 grams of HMX in Center of 8-inch Long Pipe

Photo 59: Unconfined Package Test Results - 25 grams of HMX in Center of 7-inch Long Pipe

Photo 60: Unconfined Package Test Results - 25 grams of HMX in Center of 6-inch Long Pipe

An additional trial was performed with the charge slightly offset towards the bottom of the end cap. This trial resulted in the same amount of pipe nipple deformation (36.5 cm at top, 36.7 cm at middle, 36.8 cm at bottom) but displaced towards the bottom end cap. The reaction was not contained and resulted in stripping the pipe nipple and end cap threads; the top end cap and pipe nipple flew approximately fifty feet.

Photo 61: Unconfined Package Test Results - 25 grams of HMX in Center of 6-inch Long Pipe: Containment Failure (stripped threads)

5.5.4 External Fire Test Results for HMX (Worst-Case Test Substance)

The test results for HMX, the worst-case test substance, centered in the DOT-SP 8451 4-inch diameter containment pipe in a bonfire is summarized in the following table.

Table 9: External Fire Test Results for HMX (Substance in Center of Decreasing Length Pipe)

Item	Pipe Length (in)	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Comments
1	13	25	36.3	36.3	36.3	No visible damage.
2	12	25	36.3	36.3	36.3	No visible damage.
3	11	25	36.3	36.3	36.3	No visible damage.
4	10	25	36.3	36.3	36.3	No visible damage.
5	9	25	36.3	36.3	36.3	No visible damage.
6	8	25	36.3	36.3	36.3	No visible damage.
7	7	25	36.3	36.3	36.3	No visible damage.
8	6	25	36.3	36.3	36.3	No visible damage.

The test results are shown in the following photos.

Photo 62: External Fire Test Results for Decreasing Lengths (13 to 6 inches in 1-inch increments)

5.5.5 Conclusions

Based on the test results, the DOT-SP 8451 containment pipe was able to contain a centered detonation of 25 grams of HMX with minimal deformation; the first trial, performed on a 6-inch long containment pipe, resulted in compromising the test pipe (pipe nipple blown off end cap).

NOTE: These capacities are based on a single trial; additional trials can be performed to increase the level of confidence.

6.0 FURTHER RESEARCH

1. The containment pipes appear to be undamaged from the explosives in all bonfire tests; further investigate different explosives types that may damage the shipping pipe in a bonfire scenario and compare its blast containment capacity to that of intentionally initiating the explosive.

2. Perform testing on the 6-inch diameter x 14-inch long and 8-inch diameter x 30-inch long shipping containers to determine whether the increased containment pipe volume affects its blast containment capacity.

7.0 REFERENCES

1. U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) Special Permit (SP) DOT-SP 8451, Forty-first revision, June 27, 2019.

8.0 PRODUCT CERTIFICATIONS

8.1 TNT

ACCURATE ENERGETIC SYSTEMS, LLC
EXPLOSIVE MATERIAL REPORT

AES Part No.	Specification	Material	Date
ET-1000	N/A	TNT, flake	26-Sept-19
Sales Order No.	**P.O. Number**	**Customer**	
3392	DOT1-5435	Safety Management Services	
AES Lot Number	**AES Batch Number**	**Net Amount**	**Test Conducted By**
NCH15E004-167	N/A	5 Lbs	Manufacturer

Certificate of Compliance / Analysis

Test Information				
Description	**Measure**	**Requirement Min.**	**Max.**	**Test Result**
Solidification point	°C	80.20		80.35
Moisture	Percent		0.10	0.04
Insoluble matter	Percent		0.05	0.007
Acidity as H_2SO_4	Percent		0.02	0.0007
Alkalinity		None		None
Sodium	Percent		0.001	0.0
Average flake thickness	Inch		0.025	0.021
Individual flake thickness	Inch		0.04	0.023
Color		No darker than No. 30257		Not darker than No. 30257
Form		Flake or Crystalline		Flake

Remarks

The above described material complies with specification requirements and is certified to be true, correct and hereby accepted.

Quality Assurance 26-Sept-19 Mike Capps
Quality Supervisor

QF-71-09 RA 12/15/06 Page 1 of 1

8.2 HMX

ACCURATE ENERGETIC SYSTEMS, LLC
EXPLOSIVE MATERIAL REPORT

AES Part No.	Cust. Part No.	Material	Date
EH 1003C	N/A	HMX, Grade B, Class 3	26-Sept-19
Sales Order No.	**P.O. Number**	**Customer**	
3392	DOT1-5435	Safety Management Services	
Lot Number	**Batch Number**	**Net Amount**	**Test Conducted By**
PP15-72	N/A	5 lbs	Manufacturer

Test Information

Description	Measure	Requirement Min.	Requirement Max.	Test Result
HMX	Percentage	98		99.67
RDX	Percentage		2	0.33
Acidity	Percentage		0.02	0.014
Acetone insoluble	Percentage		0.05	0.010
Insoluble particles on US STD Screen 40 US STD Screen 60	Particles		 0 5	 0 0
Melting Point	°C	277		279.0
Color	White Granules			White Granules
Granulation Through				
US STD Sieve 12	Percentage	99		100
US STD Sieve 50	Percentage	25	55	43.0
US STD Sieve 100	Percentage	10	30	13.0
US STD Sieve 200	Percentage		20	11.0

Remarks

The above described material complies with specification requirements and is certified to be true, correct and hereby accepted.

Quality Assurance 26-Sept-19 Mike Capps
Quality Supervisor

QF-71-09 RA 12/15/06 Page 1 of 1

8.3 Composition B

Product certification not currently available.

8.4 PETN

ACCURATE ENERGETIC SYSTEMS, LLC
EXPLOSIVE MATERIAL REPORT

AES Part No.	Cust. Part No.	Material	Date
EP-1003	N/A	PETN, Class 3 MIL-P-387C	26-Sept-19
Sales Order No.	**P.O. Number**	**Customer**	
3392	DOT1-5435	Safety Management Services	
Lot Number	**Batch Number**	**Net Amount**	**Test Conducted By**
19-15	10AP19G2	5 Lbs	Manufacturer

Test Information

Description	Measure	Requirement		Test Results
		Min.	Max.	
Melting Point	°C	140		140.3
Acidity Basic	Percent		0.01	AC 0:003
Bulk Density		0.95		1.10
Flow Rate	90g		80 secs	62
Vacuum Stability			5 cc	1
Acetone Insoluble	Percent		0.10	0.01
Nitrogen Content	Percent	17.50		17.65
Particles		0		0
GRANULATION				
USS Sieve 30	Percent	95		96.0
USS Sieve 200	Percent		30	1.4

Remarks

The above described material complies with specification requirements and is certified to be true, correct and hereby accepted.

Quality Assurance 26-Sept-19 Mike Capps
Mike Capps
Quality Supervisor

QF-71-09 RA 12/15/06 Page 1 of 1

8.5 Alliant Powder Bullseye® Smokeless Pistol Powder

Product certification not currently available.

8.6 CL-20

NORTHROP GRUMMAN

CERTIFICATE OF CONFORMANCE

SUPPLIER (NAME AND ADDRESS)	Part Number	REVISION	QUANTITY
Northrop Grumman Innovation Systems Promontory 9160 North Highway 83 Corinne, UT 84307	TS10978-003 LOT0026	D	5 LB
	PURCHASE ORDER NUMBER 1465		SHIPMENT NUMBER 37150

REQUIREMENT – COMPLETE ONLY THE PORTIONS OF THE FORM WHICH ARE SPECIFIED ON YOUR PURCHASE ORDER.

Quality Code

☒ CBA MATERIAL CERTIFICATION

We are attaching all chemical and physical test data covering the material and certify that these results meet the requirements detailed in Material Specification Number TS10978 Rev D. We further certify that the items in this shipment have been inspected and tested and meet the requirements of Purchase Order Number 1465.

☐ CBC MATERIAL CERTIFICATION

We certify that the chemical and physical test data (actual or nominal) covering the material id on file and available for your examination and that these results meet the requirements detailed in Material Specification Number . Furthermore, we certify that the items in this shipment have been inspected and tested and meet the requirements of Purchase and Change Order Number .

☐ CBQ SPECIAL PROCESS CERTIFICATION

We certify that the special processes have been performed in accordance with the requirements of the applicable specification(s). Objective evidence to substantiate this statement is on file and available for your examination.

SPECIFICATION NUMBER	PROCESSOR'S NAME AND ADDRESS

I CERTIFY THAT THE ABOVE STATEMENTS ARE ACCURATE

SIGNATURE OF RESPONSIBLE OFFICER	TITLE	DATE
Dale Graham	Quality Engineer	08-Nov-2019

FORM FPM-0023

Certificate of Analysis

PN TS10978-001
Grind Lot N/A
Crystallization Lot CL20XTAL-18-0002
Spec TS10978 Rev D
CL-20 DOM 15-Jun-18
Grind Date N/A

Property	Min	Max	UOM	# of tests	Results	Pass/Fail	Test Method	Document
Sampling Method	-	-	-	3	3 samples for each test	Pass	Visual	N/A
Visual Verification	-	-	-	-	Meets Specification	Pass	Visual	N/A
CL-20 Content	98.0	-	%	3	100.5, 100.1, 99.5	Pass	TS10978 4.5.2	EL18060025
Conv to Nitramine	99.0	-	%	3	99.5, 99.5, 99.5	Pass	TS10978 4.5.2	EL18060025
Impurities	-	1.0	%	3	0.5, 0.5, 0.5	Pass	TS10978 4.5.2	EL18060025
Epsilon Purity	Conforms	-			Conforms, Conforms, Conforms	Pass	TS10978 4.5.3	EL18060025
Density	2.02	-	g/cc	3	2.0276, 2.0256, 2.0219	Pass	TS10978 4.5.4	EL18060025
Acetone Insolubles	-	0.5	%	3	-0.02, -0.02, -0.02	Pass	TS10978 4.5.5	EL18060025

PN TS10978-001
Grind Lot N/A
Crystallization Lot CL20XTAL-18-0001
Spec TS10978 Rev D
CL-20 DOM 9-Jun-18
Grind Date N/A

Property	Min	Max	UOM	# of tests	Results	Pass/Fail	Test Method	Document
Sampling Method	-	-	-	3	3 samples for each test	Pass	Visual	N/A
Visual Verification	-	-	-	-	Meets Specification	Pass	Visual	N/A
CL-20 Content	98.0	-	%	3	98.8, 98.8, 98.8	Pass	TS10978 4.5.2	EL18050156
Conv to Nitramine	99.0	-	%	3	99.5, 99.5, 99.5	Pass	TS10978 4.5.2	EL18050156
Impurities	-	1.0	%	3	0.5, 0.5, 0.5	Pass	TS10978 4.5.2	EL18050156
Epsilon Purity	Conforms	-			Conforms, Conforms, Conforms	Pass	TS10978 4.5.3	EL18050156
Density	2.02	-	g/cc	3	2.0304, 2.0295, 2.0287	Pass	TS10978 4.5.4	EL18050156
Acetone Insolubles	-	0.5	%	3	-0.02, -0.02, -0.02	Pass	TS10978 4.5.5	EL18050156

Blended, Ground Lot
PN TS10978-003
Lot LOT0026
Grind Lot 218190002
Mfg NGIS, Promontory Utah
Material Ground CL-20
Crystallization Lot CL20XTAL-18-0001,-0002
Spec TS10978 Rev D
CL-20 DOM 9-Jun-18
Grind Date 2-Mar-19
Shelf Life 8-Jun-28

Property	Min	Max	UOM	# of tests	Results	Pass/Fail	Test Method	Document
50% Particle Size	1	3	µm	3	1.71, 1.66, 1.47	Pass	TS10978 4.5.9	EL19010250

I certify that the information is accurate
29-Mar-2019
Quality Engineer

NORTHROP GRUMMAN

MEMORANDUM
R&D-CY19-0897

Innovation Systems
P.O. Box 707
Brigham City, UT 84302-0707

Date: 08 November 2019
Subject: FTIR Analysis of CL-20 P/N 80018435 LOT0002

From: Melissa Mileham
Organization: Research and Development 3300

Instrument ID: Nicolet 6700

One sample of CL-20 (80018435, LOT0002, 590N-01-0057, 2180209) was submitted to the IR laboratory for analysis. FTIR analysis was completed in order to determine the polymorph of the CL-20. A small amount of sample was clamped on the Ge crystal of the single-bounce ATR Performer-IR accessory and scanned by the Nicolet 6700 FT-IR spectrometer. The resultant spectra are shown below in Figure 1.

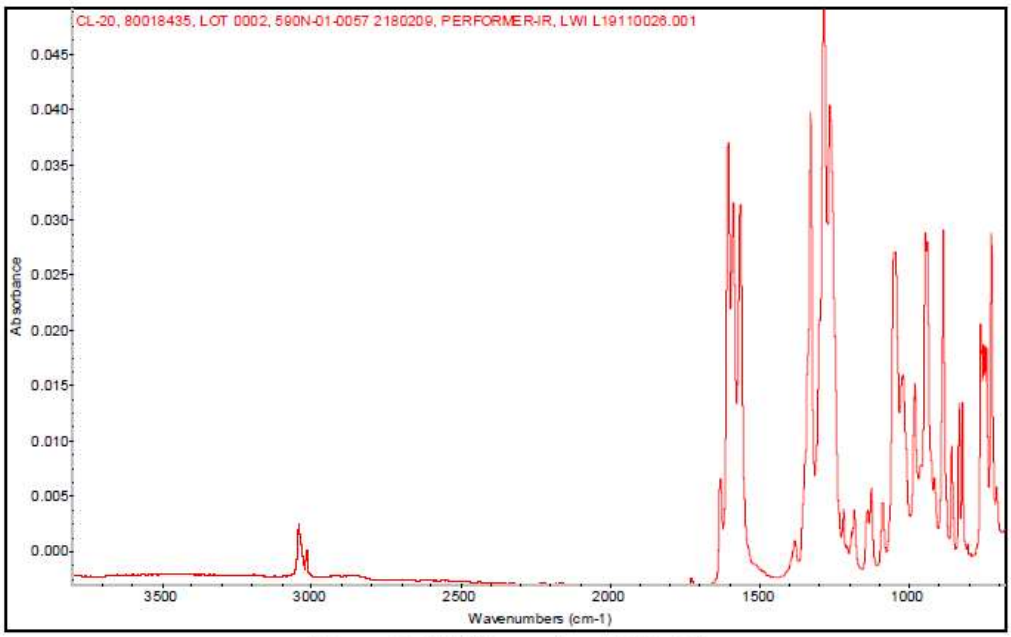
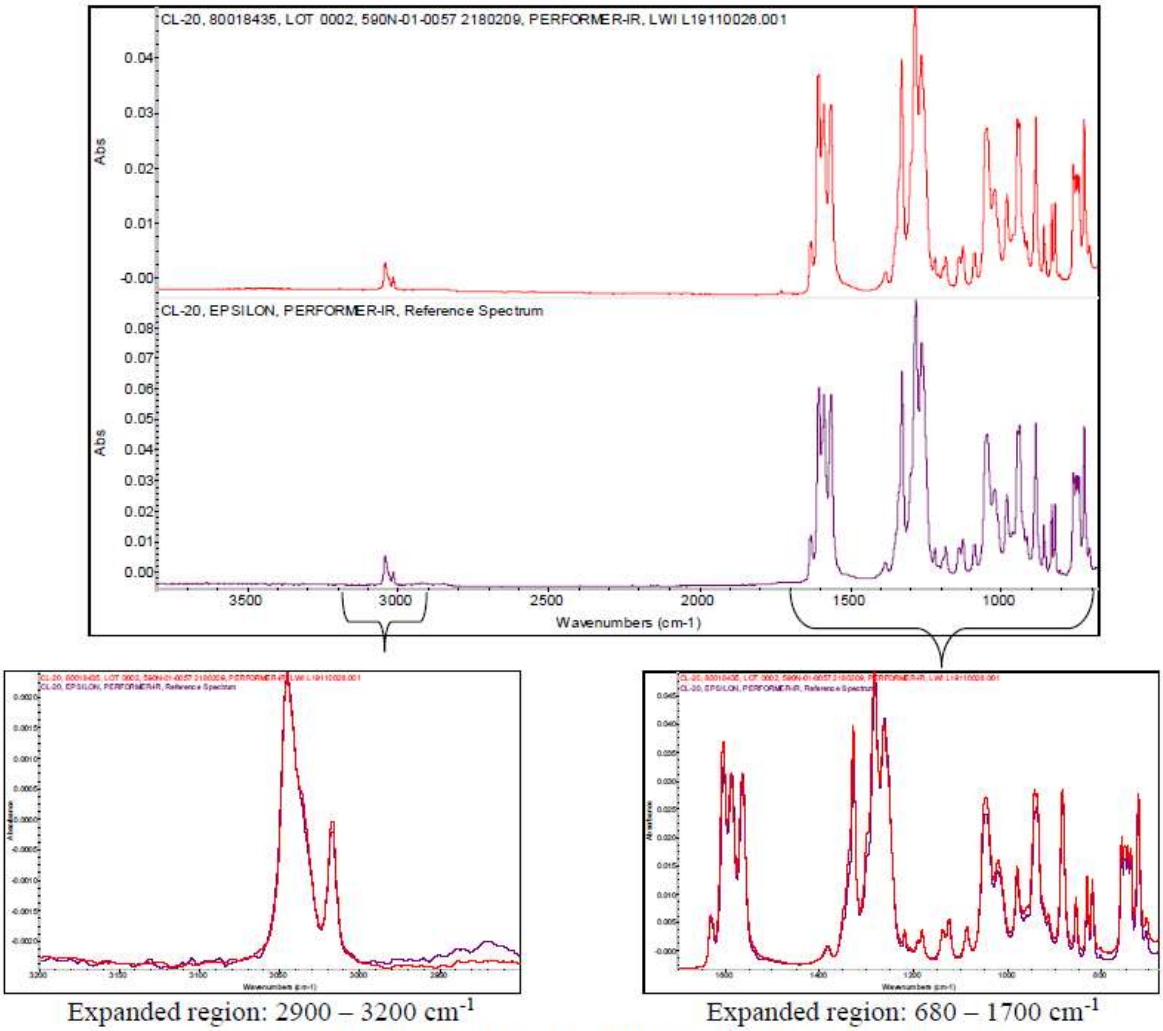


Figure 1. FTIR spectra of CL-20

The sample spectrum was then compared against reference spectra of the difference polymorphs of CL-20. The sample matched epsilon (Figure 2).



Expanded region: 2900 – 3200 cm^{-1} Expanded region: 680 – 1700 cm^{-1}

Figure 2. FTIR spectra of CL-20 sample and reference CL-20 epsilon

From the above IR data, the CL-20 samples were identified as epsilon polymorph.

X

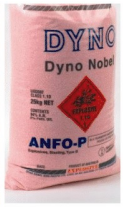
Melissa Mileham
Chemist

8.7 ANFO

ANFO (Bagged)

Prilled Ammonium Nitrate

Technical Information



Description

ANFO is a nominal 94:6 (wt%) blend of porous ammonium nitrate prill (Detaprill®) and fuel oil. It is a dry, free flowing explosive; formulated to ensure the appropriate oxygen balance providing optimal energy and sensitivity.

Application

ANFO has zero water resistance and has a wide variety of applications in dry hole blasting conditions. It is one of the most cost efficient blasting agents available for use in small, medium or large diameter applications. When pneumatically loaded; ANFO may also be used effectively in underground development and tunnelling applications.

Advantages

- ANFO is a dry and free flowing product, allowing delivery by loose pour or pneumatic loading.
- The low bulk density of ANFO provides excellent charge distribution in the blasthole.
- ANFO provides excellent heave energy.

Properties

	Poured	Pneumatically Loaded
Density (g/cm^3) [1]	0.82	0.95
Minimum Hole Diameter (mm)	75	25
Energy (MJ/kg) [2]	3.7	3.7
Typical VOD (m/s) [3]	2500 - 4500	2000 - 4000
RWS % [4]	100	100
RBS % [5]	100	116

NOTES:

1. Values are indicative average densities only, determined under laboratory conditions by Dyno Nobel technical personnel at Dyno Nobel's Mt Thorley Technical Centre. Observed densities may differ or vary under field conditions. Nominal in hole density only.
2. All Dyno Nobel energy values are calculated using a proprietary Dyno Nobel thermodynamic code – Prodet. Other programs may give different values.
3. These results represent a range of VODs collected from numerous Dyno Nobel blast sites throughout the Asia Pacific region over a period of time. The velocity of detonation actually recorded in use is dependent upon many factors, including: the initiation system used, the product density, blasthole diameter and ground confinement. The values stated are typical of those recorded for the product in various hole diameters, densities and ground types, and may not be achievable under all circumstances.
4. Relative Weight Strength (RWS) and Relative Bulk Strength (RBS) are determined using a density of 0.82g/cm^3 and an energy of 3.7MJ/kg for ANFO.
5. RBS depends on the final density of the product at the time of loading.

Hazardous Shipping Description
Explosive, Blasting, Type E 1.1D UN 0082

Recommendations

Priming Requirements – It is recommended that ANFO should be primed with a cast booster for all hole diameters. Depending on the application, ANFO may be primed with a suitable diameter detonator sensitive cartridge explosive (Powermite® Pro). For specific priming requirements, please contact your Dyno Nobel representative. Additional boosters should be used when the column height exceeds 10 metres or where there is risk of column disruption.

Maximum Hole Depth – ANFO can be detonated successfully in depths up to 75m.

Shelf Life – ANFO has a maximum shelf life of six (6) months dependent on temperature and humidity conditions. Storage in a high humidity and high temperature environment will accelerate product breakdown and should be avoided. Signs of ANFO degradation are hardening or caking which can lead to difficulty in loading and as a result, may lead to poor blasting performance.

Sleep Time – Under normal conditions in dry and stemmed blastholes, ANFO may be slept for periods up to six (6) weeks. The sleep time may be limited to the recommended sleep time of the initiating system. The presence of water will dramatically reduce the sleep time. For applications where unusual or specific conditions exist please consult your local Dyno Nobel representative for advice.

Reactive Ground Conditions – ANFO is not designed for use in conditions where reactive sulphides are present.

Ground Temperature – ANFO is suitable for use in ground with a temperature of 0°C to a maximum of 55°C. For applications in ground with temperatures outside this range, contact your Dyno Nobel representative.

Packaging

Bagged ANFO is available in packaged form varying from bulk bags (500kg) through to smaller plastic bags (10, 20 and 25kg). All bags are delivered on one (1) tonne product only weight pallets i.e. 2 x 500kg, 100 x 10kg, 50 x 20kg and 40 x 25kg plastic bags per pallet.

Safe handling, transportation and storage

First Aid – You can find detailed first aid information on the relevant Dyno Nobel Safety Data Sheet. Refer to www.dynonobel.com for more information if required.

Safety - All explosives are classified as dangerous goods and can cause personal injury and damage to property if used incorrectly.

Transportation and Storage - All explosives must be handled, transported and stored in accordance with all relevant regulations. Stock should be rotated such that older product is used first.

Version 7
May 2016

Dyno Nobel Asia Pacific Pty Limited (ACN 003 269 010) is a subsidiary of
Incitec Pivot Limited (ACN 004 080 264) Level 8, 28 Freshwater Place, Southbank Vic 3006
Phone 1800 251 872 Fax 07 3026 3999 www.dynonobel.com

DYNO® Dyno Nobel
Groundbreaking Performance®

8.8 Composition A-5

ACCURATE ENERGETIC SYSTEMS, LLC
EXPLOSIVE MATERIAL REPORT

AES Part No.	Cust. Part No.	Material	Date
ER 5150	N/A	Comp A-5, Mil-Spec	27-Sept-19
Sales Order No.	**P.O. Number**	**Customer**	
3392	DOT1-5435	Safety Management Services	
Lot Number	**Batch Number**	**Net Amount**	**Test Conducted By**
BAE16M111-059	A501-9373	5 lbs	Manufacturer

Test Information

Description	Measure	Requirement		Test Results
		Min.	Max.	
RDX	Percent	98.5	99.0	98.7
Stearic Acid	Percent	1.0	1.5	1.3
Insoluble Particles USSS 40 Sieve USSS 60 Sieve			 0 5	 0 0
Bulk Density	g/ml	0.95		0.95
Moisture	Percent		0.10	0.08
Residual Cyclohexanone	Percent		0.30	0.06
Workmanship				PASS
Advisory Screens - Granulation Through				
USS Sieve 12	Percent	99.0		100.0
USS Sieve 200	Percent		2.4	0.2

Remarks

The above described material complies with specification requirements and is certified to be true, correct and hereby accepted.

Quality Assurance 27-Sept-19 Mike Capps
Quality Supervisor

QF-71-09 RA 12/15/06 Page 1 of 1

Evaluation of Shipping Pipes used to Transport Explosives under DOT-SP 8451

Final Report (Volume 2)
Test Report for Tasks 5 - 6 (Explosive Articles)

DOT PHMSA Contract # DTPH5616D00001, Task Order 0003
SwRI® Project 24731

Prepared by:

Troy A. Gardner, P.E., CSP (SMS)
Jared S. Teter, Ph.D. (SMS)
Jason Ford (SMS)
Derek J. Holmstead (SMS)
Michael G. MacNaughton, Ph.D., P.E. (SwRI)

Prepared for:

DOT PHMSA
1200 New Jersey Avenue SE
Washington, DC 20590

December 15, 2020

SOUTHWEST RESEARCH INSTITUTE®
6220 Culebra Road • P.O. Drawer 28510
San Antonio, Texas 78228-0510

SOUTHWEST RESEARCH INSTITUTE®
6220 CULEBRA ROAD • P.O. DRAWER 28510
SAN ANTONIO, TEXAS 78228-0510

Evaluation of Shipping Pipes used to Transport Explosives under DOT-SP 8451

Final Report (Volume 2)
Test Report for Tasks 5 - 6 (Explosive Articles)

DOT PHMSA Contract # DTPH5616D00001, Task Order 0003
SwRI® Project 24731

Prepared by:

Troy A. Gardner, P.E., CSP (SMS)
Jared S. Teter, Ph.D. (SMS)
Jason Ford (SMS)
Michael G. MacNaughton, Ph.D., P.E. (SwRI)

Prepared for:

DOT PHMSA
1200 New Jersey Avenue SE
Washington, DC 20590

Approved by:

Michael G. MacNaughton, Ph.D., P.E.
Vice President
Chemistry and Chemical Engineering Division

TABLE OF CONTENTS

TABLES

PHOTOS

FIGURES

1.0 OBJECTIVE

The U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) requested that Southwest Research Institute (SwRI) determine the blast-containment capacity of the U.S. DOT PHMSA Special Permit (DOT-SP) 8451 containment pipe for explosive articles centered in the containment pipe or in contact with the pipe's sidewall when intentionally initiated or when exposed to a fire.

2.0 EXECUTIVE SUMMARY

Based on the test results, articles producing a shaped-charge jet effect or penetrating fragments, excluding those produced by projectiles containing high explosives and/or incendiaries, may perforate or breach the DOT-SP 8451 shipping pipe. For blast attenuation/mitigation, the tested coarse perlite fill, 0.22-inch thick steel lining, and 0.50-inch thick rubber lining generally reduced the damage to the DOT-SP 8451 shipping pipe from shaped-charge jets and penetrating fragments, but failed to consistently prevent perforation of the shipping pipe. Therefore, the tested blast attenuation/mitigation strategies are not recommended for adoption/inclusion in the DOT-SP 8451 special permit.

3.0 SUMMARY AND CONCLUSIONS

Safety Management Services, Inc. (SMS) conducted testing under contract to Southwest Research Institute (SwRI) to determine the blast-containment capacity of the DOT-SP 8451 containment pipe. Testing consisted of UN Series 6 tests on the unpackaged containment pipe at SMS's test site in Tooele, Utah. Tests were witnessed by Jason Ford and performed in accordance with the United Nations (UN) Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, Sixth revised edition (2015).

Test articles included explosives such as linear shaped charges, conical shaped charges, detonators, fuzes, high explosive projectiles, metal-cased boosters, detonating cord, cast boosters, ammunition cartridges, fragmenting grenades, etc. Some detonating articles, such as shaped charges, may only burn when exposed to flame in a bonfire test. An M7 non-electric blasting cap (detonator) was included in contact with select articles intended to function by detonation to encourage/promote/force their detonation in the bonfire test, thereby obtaining worst-case insults to the shipping pipe during the bonfire tests to account for future worst-case articles.

Full examination of the test results is provided in Section 6.3. Based on the test results, the explosive articles in the following table resulted in no external damage to the DOT-SP 8451 shipping pipe in the UN Series 6 tests.

Table 1: Test Samples with No External Damage to the DOT-SP 8451 Shipping Pipe

Sample ID	Article Type
11B1	Cannon with armor piercing projectile, medium diameter
11B2	Cannon with armor piercing projectile, medium diameter
15C	Rocket motor, large
16C	Thermite cutting torch, large

Explosive articles that were unable to perforate/breach the DOT-SP 8451 shipping pipe in the UN Series 6 tests are listed in the following table.

Table 2: Test Samples that did NOT Perforate/Breach the DOT-SP 8451 Shipping Pipe

Sample ID	Article Type
1B	Booster (non-cased), medium
1C	Booster (non-cased), large
3A	Detonator, small
6D	Linear shaped charge, X-large (face-to-face)
8A	Conical shaped charge, small (face-to-face)
9A	Detonating cord, small
9B	Detonating cord, medium
12B	Ammunition cartridge, medium with HEI projectile
13B1	High explosive projectile, fragmenting, medium
13B2	High explosive projectile, fragmenting, medium
13C*	High explosive projectile, fragmenting, large
14B	Fuze, medium
*Perforated the shipping pipe only when in contact with the pipe's sidewall	

Conversely, the explosive articles in the following table were able to perforate/breach the shipping pipe in the UN Series 6 tests.

Table 3: Test Samples that Perforated/Breached the DOT-SP 8451 Shipping Pipe

Sample ID	Article Type
2B	Booster (metal cased), medium
4C1	Grenade, fragmenting (pre-formed), large
4C2	Grenade, fragmenting (pre-formed), large
5A	Linear shaped charge, small
5B	Linear shaped charge, medium
5C	Linear shaped charge, large
5D	Linear shaped charge, X-large

Sample ID	Article Type
6A	Linear shaped charge, small (face-to-face)
6C	Linear shaped charge, large (face-to-face)
7A	Conical shaped charge, small (stacked face-to-end)
7B	Conical shaped charge, medium (stacked face-to-end)
7C	Conical shaped charge, large (single)
8B	Conical shaped charge, medium (face-to-face)
8C	Conical shaped charge, large (face-to-face)
10A1	Fragmenting warhead/bomblets, thin wall
10A2	Fragmenting warhead/bomblets, thin wall (without hardened ball)
10B	Fragmenting warhead/bomblets, medium wall
10C	Fragmenting warhead/bomblets, thick wall
13C*	High explosive projectile, fragmenting, large
17A	Conical shaped charge, small (interconnected & facing sideways)
17B	Conical shaped charge, medium (interconnected & facing sideways)
17C	Conical shaped charge, large (facing sideways)
*Perforated the shipping pipe only when in contact with the pipe's sidewall	

Based on these test results, articles producing a shaped-charge jet effect or penetrating fragments, excluding those produced by projectiles containing high explosives and/or incendiaries, may perforate or breach the DOT-SP 8451 shipping pipe. An article that was fully contained when centered within the pipe, when placed in contact with the sidewall, may result in perforation/breaching of the shipping pipe. There did not appear to be a clear relationship between the ability to perforate/breach the DOT-SP 8451 shipping pipe and a unit's individual net explosive weight when packed in bulk.

Blast attenuation/mitigation strategies were pursued to determine whether the hazardous effects could be suppressed and contained within the shipping pipe. The test results are summarized in the following table for the explosive articles with blast attenuation/mitigation employed (five articles each for perlite fill, 0.22-inch thick steel lining, and 0.50-inch thick rubber lining) in the UN Series 6 (d) Unconfined package and 6 (c) External fire tests.

Table 4: Summary of UN Series 6 Test Results for Blast-Mitigated Explosive Articles in the DOT-8451 Shipping Pipe - Percent Increase in Pipe Circumference

Sample ID	N.E.W.		Centered		Blast Attenuation/Mitigation Strategy					
					Perlite		Steel		Rubber	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)	6 (d)	6 (c)	6 (d)	6 (c)
6C	25.0	50.0	P	X	P	1.6%	1.9%	P	12.9%	X
7C	25.0	25.0	P	17.3%	P	7.1%	P	P	P	0.8%
8C	25.0	50.0	P	1.6%	8.2%	P	4.4%	P	9.9%	P

Sample ID	N.E.W.		Centered		Blast Attenuation/Mitigation Strategy					
					Perlite		Steel		Rubber	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)	6 (d)	6 (c)	6 (d)	6 (c)
10A2	45.8	45.8	P	P	P	P	P	X	P	X
17B	11.0	33.0	P	P	P	X	P	P	P	P

For blast attenuation/mitigation, the tested coarse perlite fill, 0.22-inch thick steel lining, and 0.50-inch thick rubber lining generally reduced the damage to the DOT-SP 8451 shipping pipe from shaped-charge jets and penetrating fragments, but failed to consistently prevent perforation of the shipping pipe. Therefore, the tested blast attenuation/mitigation strategies are not recommended for adoption/inclusion in the DOT-SP 8451 special permit.

4.0 BACKGROUND

Thirty-nine test samples/configurations were selected for the initial testing of articles centered in the DOT-SP 8451 shipping container. Test samples were recommended by SMS based upon their potential hazard/threat, product availability, and variety. The following table summarizes the initial test samples.

Table 5: Initial Test Samples Selected for DOT-SP 8451 Containment Pipe Testing

Sample ID	Article Type
1B	Booster (non-cased), medium
1C	Booster (non-cased), large
2B	Booster (metal cased), medium
3A	Detonator, small
4C1	Grenade, fragmenting (pre-formed), large
4C2	Grenade, fragmenting (pre-formed), large
5A	Linear shaped charge, small
5B	Linear shaped charge, medium
5C	Linear shaped charge, large
5D	Linear shaped charge, X-large
6A	Linear shaped charge, small (face-to-face)
6B	Linear shaped charge, medium (face-to-face)
6C	Linear shaped charge, large (face-to-face)
6D	Linear shaped charge, X-large (face-to-face)
7A	Conical shaped charge, small (stacked face-to-end)
7B	Conical shaped charge, medium (stacked face-to-end)
7C	Conical shaped charge, large (single)
8A	Conical shaped charge, small (face-to-face)
8B	Conical shaped charge, medium (face-to-face)
8C	Conical shaped charge, large (face-to-face)
9A	Detonating cord, small

Sample ID	Article Type
9B	Detonating cord, medium
10A1	Fragmenting warhead/bomblets, thin wall
10A2	Fragmenting warhead/bomblets, thin wall (without hardened ball)
10B	Fragmenting warhead/bomblets, medium wall
10C	Fragmenting warhead/bomblets, thick wall
11B1	Cannon with armor piercing projectile, medium diameter
11B2	Cannon with armor piercing projectile, medium diameter
11C	Cannon with armor piercing projectile, large diameter
12B	Ammunition cartridge, medium with HEI projectile
13B1	High explosive projectile, fragmenting, medium
13B2	High explosive projectile, fragmenting, medium
13C	High explosive projectile, fragmenting, large
14B	Fuze, medium
14C	Fuze, large
15C	Rocket motor, large
16C	Thermite cutting torch, large
17A	Conical shaped charge, small (interconnected & facing sideways)
17B	Conical shaped charge, medium (interconnected & facing sideways)
17C	Conical shaped charge, large (facing sideways)

5.0 DESCRIPTION OF DOT-SP 8451 TEST SAMPLES

5.1 DOT-SP 8451 Containment Pipe

The U.S. DOT Pipeline and Hazardous Materials Safety Administration (PHMSA) Special Permit (DOT-SP) 8451 containment pipe is a 4-inch × 14-inch Schedule 80 seamless steel pipe nipple (0.34-inch nominal thickness) closed at both ends with 3,000-psi forged steel end caps per ASTM 105. The pipe threads are cut so that the end caps can be screwed on a minimum of five threads by hand.

Photo 1: DOT-SP 8451 Containment Pipe

5.2 Blast Mitigation Materials

5.2.1 *Perlite Fill*

The perlite fill was a super coarse perlite with an average size range of 0.13 - 0.19 inches. Perlite is a unique volcanic mineral which expands from four to twenty times its original volume when it is heated. When expanded, each granular, snow-white particle of perlite is sterile with a neutral pH and contains many tiny, closed cells or bubbles. The surface of each particle is covered with tiny cavities which provide an extremely large surface area. The perlite was supplied by HydroGarden Ltd of Coventry, England under the label PLANT!T (SKU GMPER100L) for the brand GROW!T.

Photo 2: PLANT!T Super Coarse Perlite

For testing, the articles were centered within each perlite-filled pipe.

5.2.2 *Steel Lining (0.22-inch thick)*

The steel lining was nominally 0.22-inches thick and was comprised primarily of a 3-inch × 15-inch Schedule 40 seamless steel pipe.

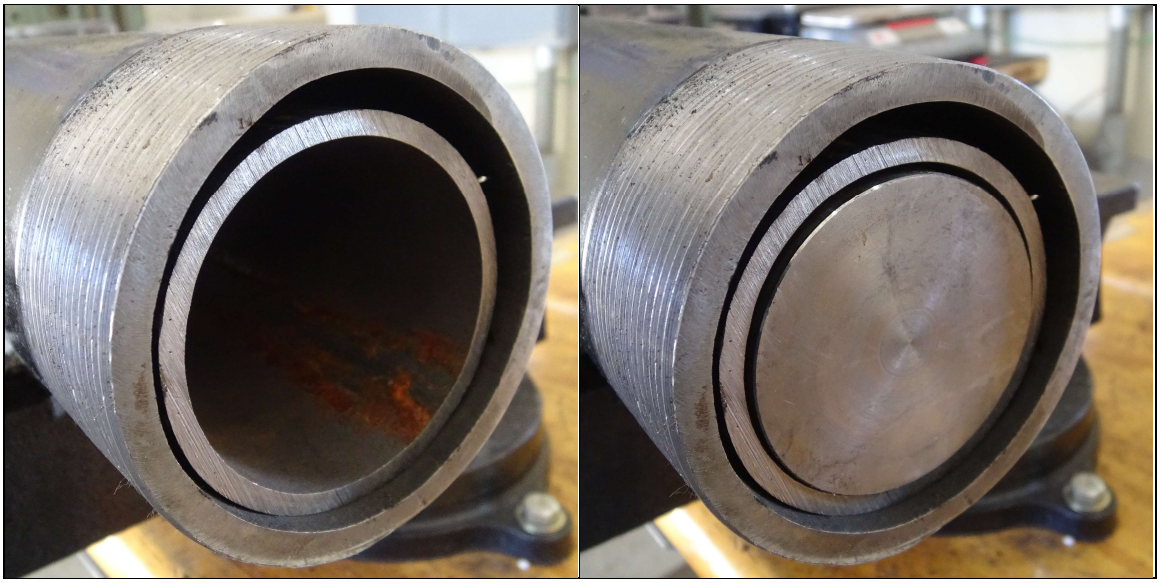


Photo 3: Steel Lining (0.22-inch thick)

5.2.3 *Rubber Lining (0.50-inch thick)*

The rubber lining was identified as 0.50-inch thick EPDM Commercial Grade (CG) 60A rubber sheet composed of a 10% Ethylene Propylene Diene Monomer (EPDM) base and Styrene Butadiene Rubber (SBR). The material has a durometer of Shore 60A hardness with a tensile strength of 725 psi (5 MPa), and a minimum elongation of 300%; the rubber was firm yet pliable. A single-sheet thickness of rubber was used to line the steel pipe and end caps.

Photo 4: EPDM CG 60A Rubber Sheet

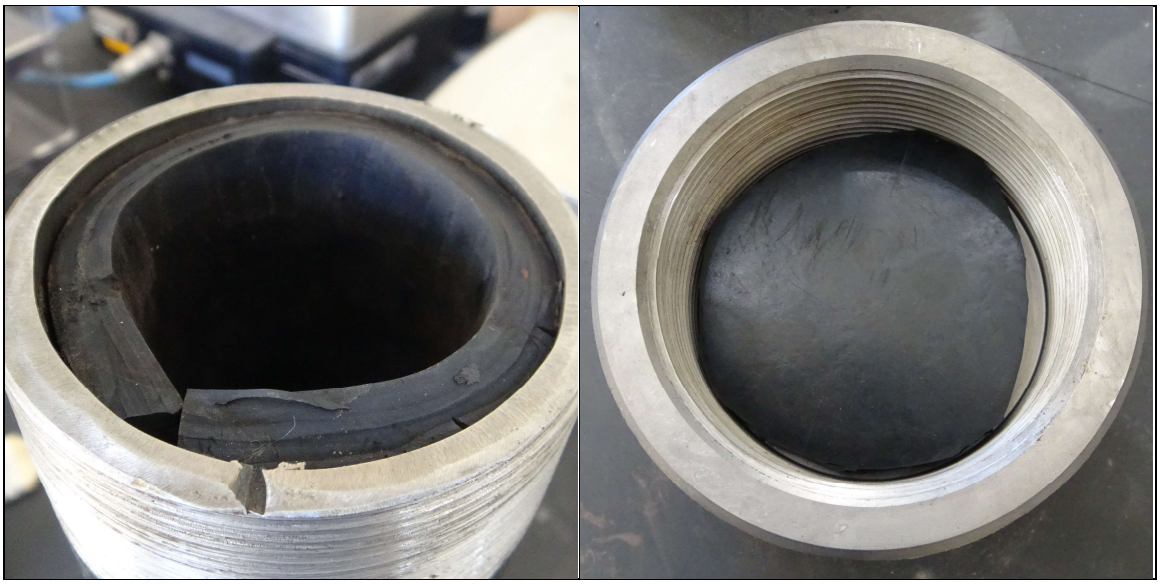


Photo 5: Rubber Lining (0.50-inch thick)

5.3 Sample ID #1B - Booster (non-cased), medium

The article selected to represent this group was identified as Trojan 10-gram Stinger booster. These items were manufactured by Dyno Nobel Inc. at its Wolf Lake, Illinois facility. The composition of the product is listed in the following table.

Table 6: Composition of the Coupled 10-gram Trojan Stinger Boosters

Explosive Component	Constituents	Weight (%)	Explosive Weight (g)
Trojan 10-gram Stinger booster, three each	PETN	60	10 each
	TNT	40	
	Subtotal	100	
		TOTAL	30

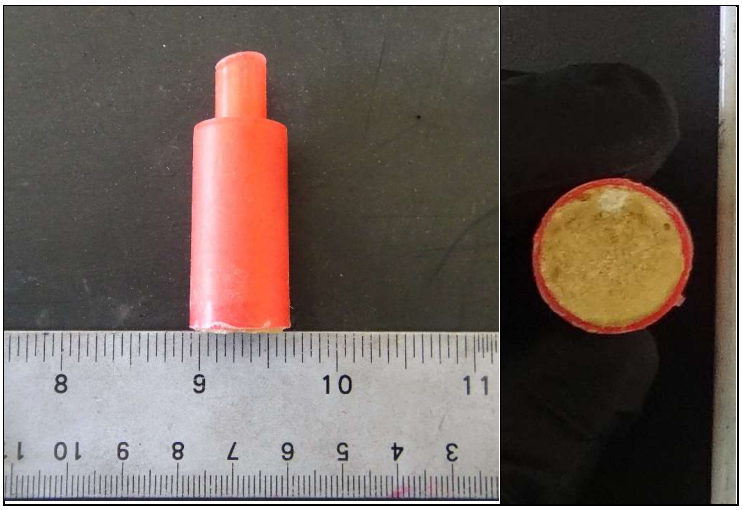


Photo 6: 10-gram Trojan Stinger Booster

5.4 Sample ID #1C - Booster (non-cased), large

The article selected to represent this group was identified as a Trojan 20-gram Stinger booster coupled to a Trojan 10-gram Stinger booster. These items were manufactured by Dyno Nobel Inc. at its Wolf Lake, Illinois facility. The composition of the product is listed in the following table.

Table 7: Composition of the Coupled 20-gram and 10-gram Trojan Stinger Boosters

Explosive Component	Constituents	Weight (%)	Explosive Weight (g)
Trojan 20-gram Stinger booster	PETN	60	20
	TNT	40	
	Subtotal	100	
Trojan 10-gram Stinger booster	PETN	60	10
	TNT	40	
	Subtotal	100	
		TOTAL	30

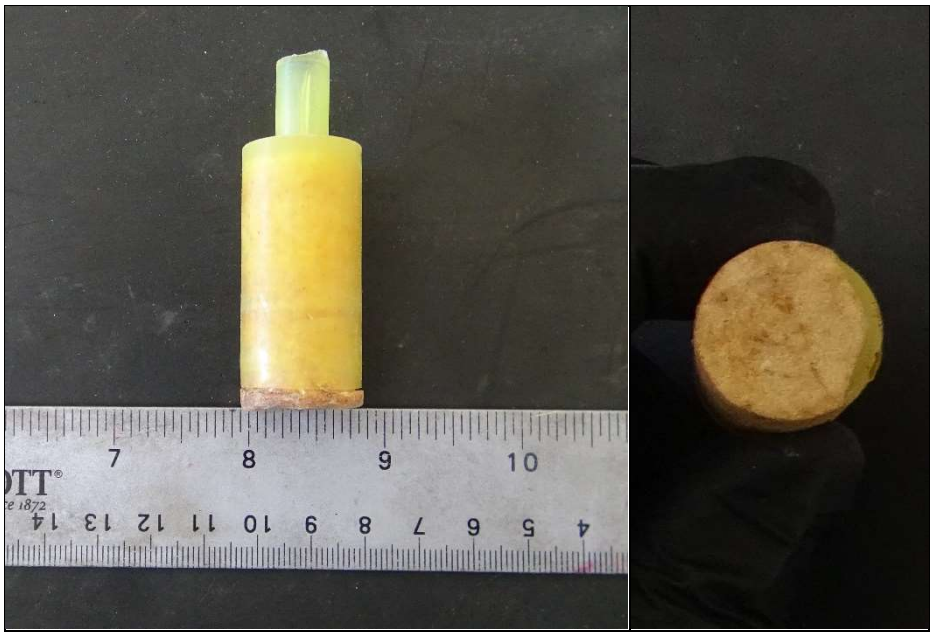


Photo 7: 20-gram Trojan Stinger Booster

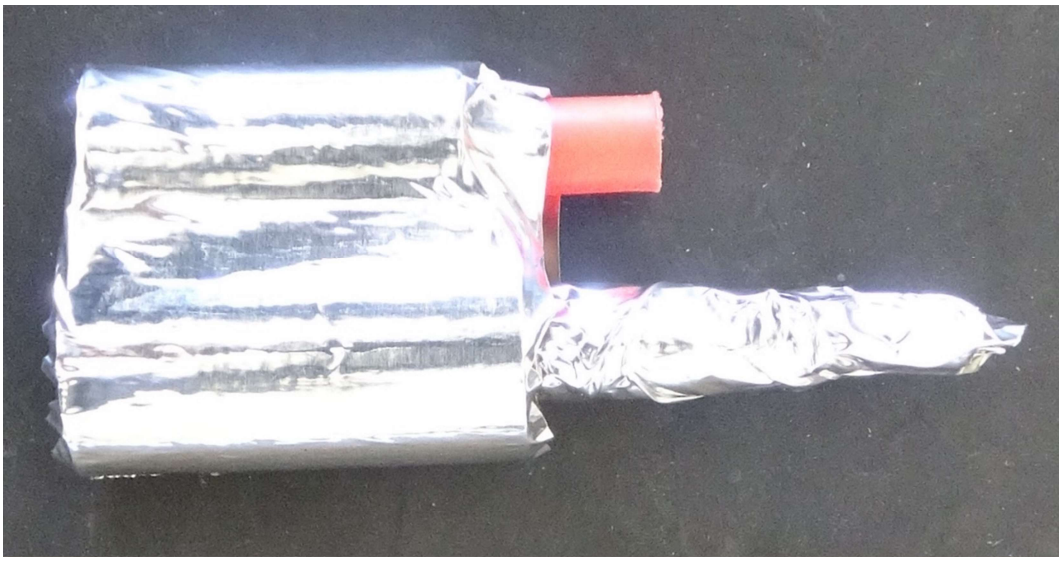


Photo 8: Sample ID #1C - Booster (non-cased), large

5.5 Sample ID #2B - Booster (metal cased), medium

The article selected to represent this group was identified as a M423/M427 Fuze Booster Assembly. In absence of explosives weight from the manufacturer, the U.S. Army reports that the M423/M427 Fuze contains 9 grams net explosives weight[1]. Three articles were used per trial

[1] Department of the Army Technical Manual (TM) 43-0001-30, Army Ammunition Data Sheets for Rockets, Rocket Systems, Rocket Fuzes, Rocket Motor (Federal Supply Class 1340), December 1981, page 4-3 for "FUZE, POINT DETONATING, M423 (M427)".

(9 grams each, 27 grams total). From the drawing in the referenced Army manual, the fuze booster assembly has a wall thickness of 0.130 - 0.18 inches.

Photo 9: M423/M427 Fuze Booster Assembly

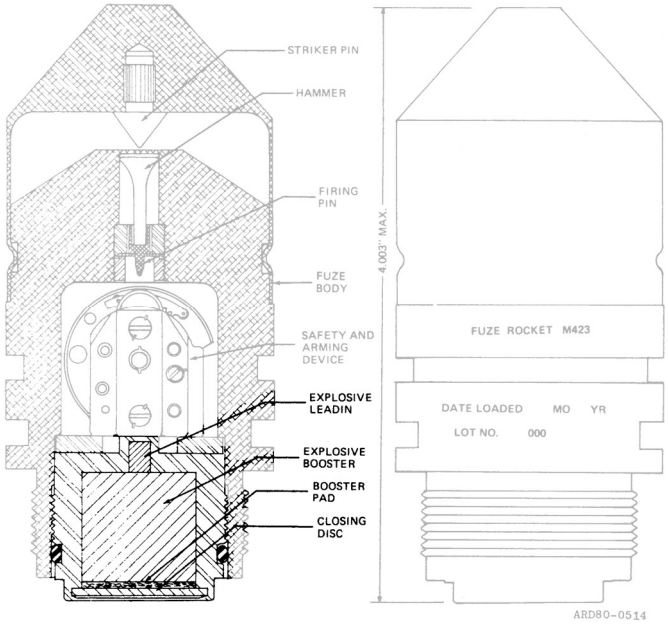


Figure 1: Drawing of the M423/M427 Fuze showing Explosive Booster

The articles were stacked on each other and initiated with a detonator in contact with and parallel to the explosive lead-in.

Photo 10: Sample ID #2B - Booster (metal cased), medium

5.6 Sample ID #3A - Detonator, small

The article selected to represent this group was identified as an M7 Non-electric Blasting Cap and were supplied by Tripwire Operations Group. The detonators were manufactured for Enaex by IBQ Industrias Químicas S/A of Quatros Barras-PR, Brasil and were marked with "IBQ 0800-11-1767 PERIGO A 00221101820 30/05/14". Twenty-three articles were used per trial. The composition of the product is listed in the following table.

Table 8: Composition of the M7 Non-electric Blasting Cap

Explosive Component	Constituents	Weight (%)	Explosive Weight (g)
Ignition charge	Lead styphnate	100	
Intermediate charge	Lead azide	100	
Base charge	RDX	100	
		TOTAL	

In absence of explosives weight from the manufacturer, the U.S. Army reports that the M7 non-electric detonator contains 1.3 grams net explosives weight[2], which yields a total of 29.9 grams per trial.

[2] Department of the Army Technical Manual (TM) 43-0001-38, Army Ammunition Data Sheets for Demolition Materials, July 1994, page 2-5 for "CAP, BLASTING, NONELECTRIC: M7" lists a DODIC of M131 for the M7 Non-electric Blasting Cap. The U.S. Army Defense Ammunition Center Hazard Classification of United States Military Explosives and Munitions, Revision 15, June 2012 (known as the "Yellow Book") lists a net explosives weight for Quantity Distance purposes in kilograms (NEWQDKG) of 0.0013 for DODIC M131 (CAP, BLAST NON-ELEC SPEC/M7).

Photo 11: M7 Non-electric Blasting Cap

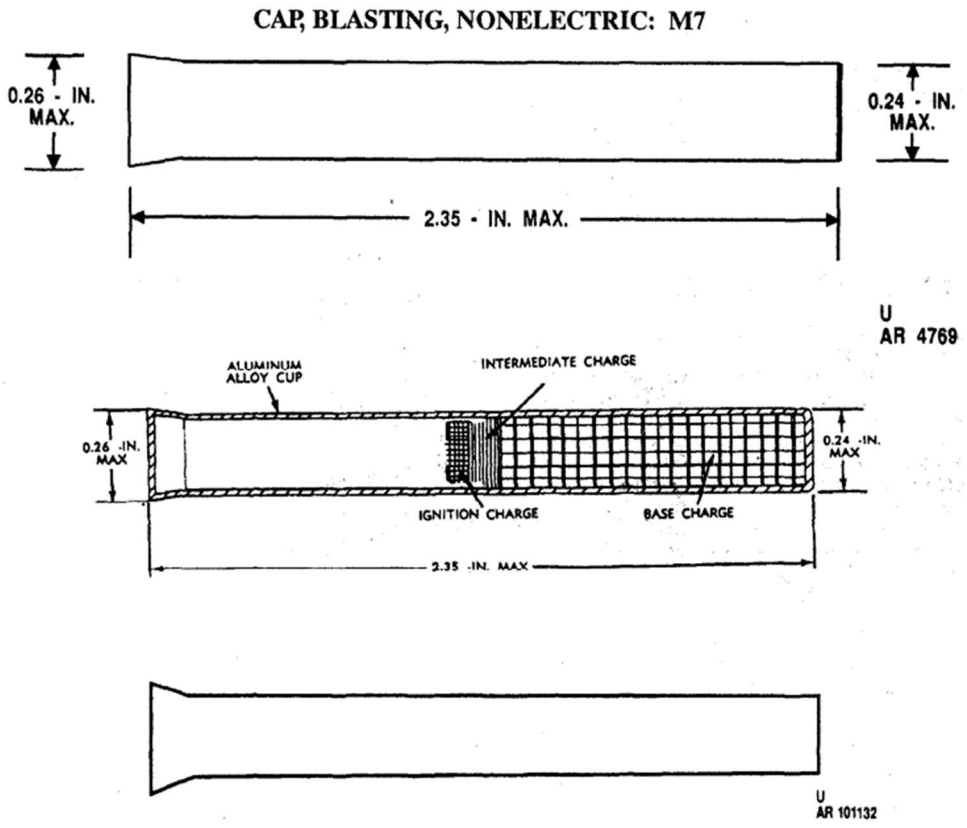


Figure 2: Drawing of the M7 Non-electric Blasting Cap

The detonators were bundled together and initiated at the center of the cluster.

Photo 12: Sample ID #3A - Detonator, small

5.7 Sample ID #4C1 - Grenade, fragmenting (pre-formed), large

The article selected to represent this group was identified as a modified M42 grenade (shaped charge liner removed). The item was provided by the U.S. Army and contained 30.5 grams of Composition A-5[3].

Photo 13: Modified M42 Grenade (shaped charge liner removed)

[3] TM 43-0001-28, Army Ammunition Data Sheets for Artillery Ammunition, "GRENADE: GENERAL PURPOSE, M42", page 8-51.

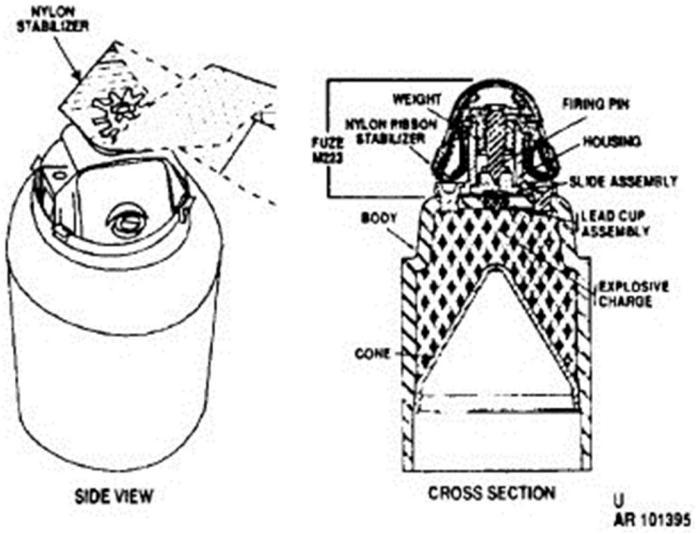


Figure 3: Drawing of the M42 Grenade

The article was initiated by inserting the detonator down the center of the cone until it was in contact with the cone's vertex and perpendicular to its base.

Photo 14: Sample ID #4C1 - Grenade, fragmenting (pre-formed), large

5.8 Sample ID #4C2 - Grenade, fragmenting (pre-formed), large

The article selected to represent this group was identified as a 40 mm M430A1 body loading assembly projectile. The outer casing of the article is designed to fragment; the explosive charge is equipped with a cone-shaped inner copper liner designed to create a shaped charge jet. The item was provided by American Ordnance and contained 37.5 grams of Composition A-5.

Photo 15: 40mm M430A1 Body Loading Assembly Projectile

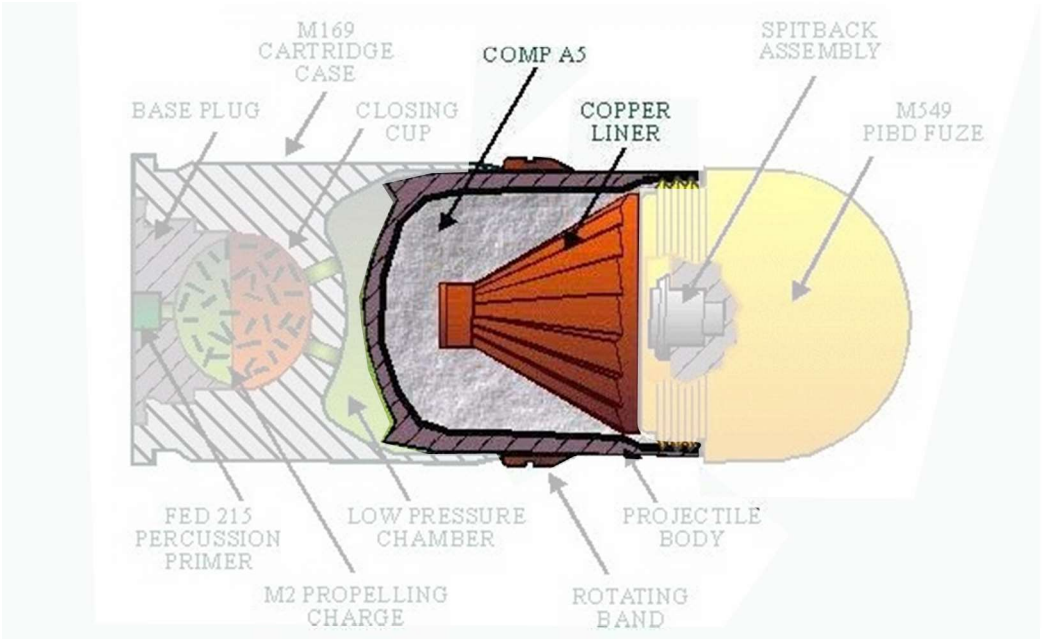


Figure 4: Drawing of the 40 mm M430A1 Body Loading Assembly Projectile

The article was initiated by inserting the detonator down the center of the cone until it was in contact with the cone's vertex and perpendicular to its base.

Photo 16: Sample ID #4C2 - Grenade, fragmenting (pre-formed), large

5.9 Sample ID #5A/#6A - Linear Shaped Charge, small

The article selected to represent this group was identified as P/N FL-Y2300300 Linear Shaped Charge manufactured by Accurate Energetic Systems, LLC at its McEwen, Tennessee facility. The product is constructed of a copper sheath material and contains 300 gr/ft (1.62 grams/in) of RDX. The 300 gr/ft Linear Shaped Charge had a width of 0.46 inches and length of 15.375 inches for a total of 25 grams each. The composition of the product is listed in the following table.

Table 9: Composition of the P/N FL-Y2300300 300gr/ft Linear Shaped Charge

Explosive Component	Constituents		Weight (%)	Explosive Weight
Core Material	Cyclotrimethylenetrinitramine (RDX)		92.5 - 99.3	300 gr/ft @ 15.375 in
	Binder		0.7 - 5	
	Graphite		0 - 0.5	
	Calcium stearate		0 - 0.5	
			TOTAL	25 grams

Photo 17: P/N FL-Y2300300 300-gr/ft Linear Shaped Charge

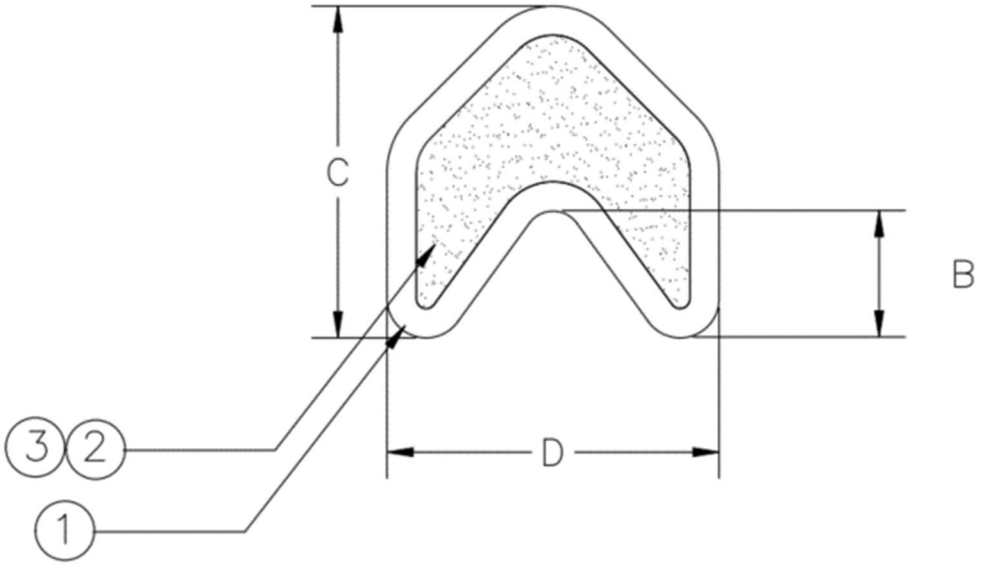


Figure 5: Drawing of the P/N FL-Y2300300 300-gr/ft Linear Shaped Charge

The article was initiated by placing a detonator on one end, perpendicular to the linear shaped charge.

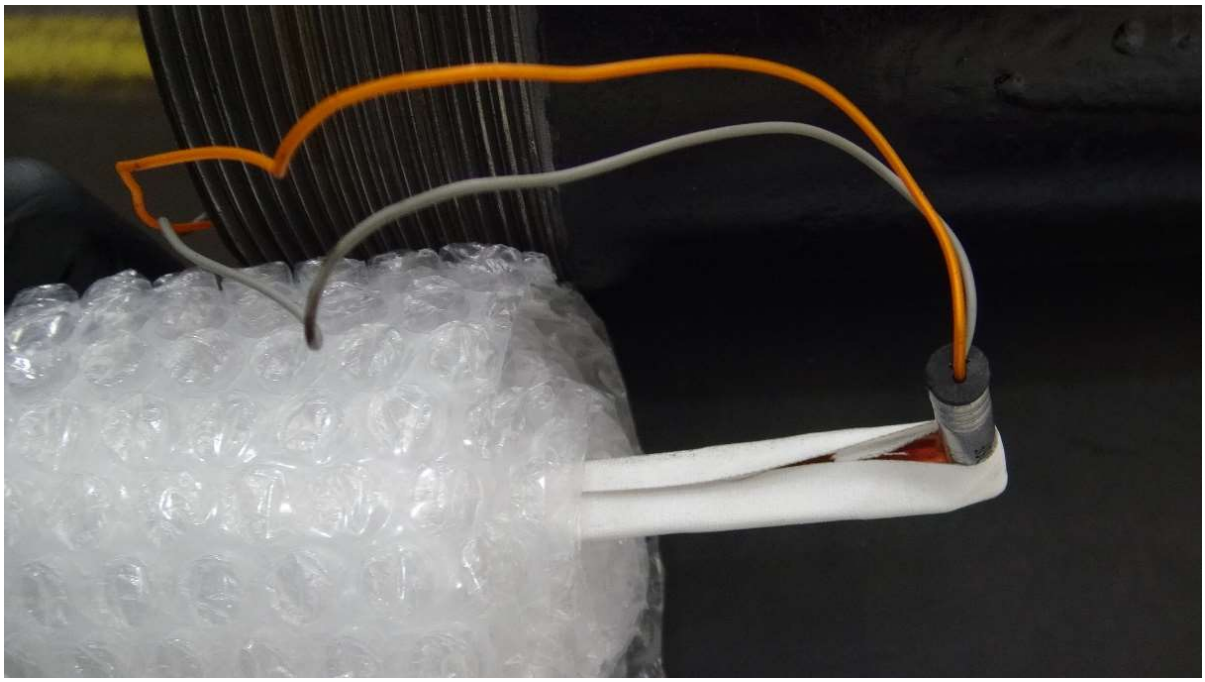


Photo 18: Sample ID #5A - Linear Shaped Charge, small

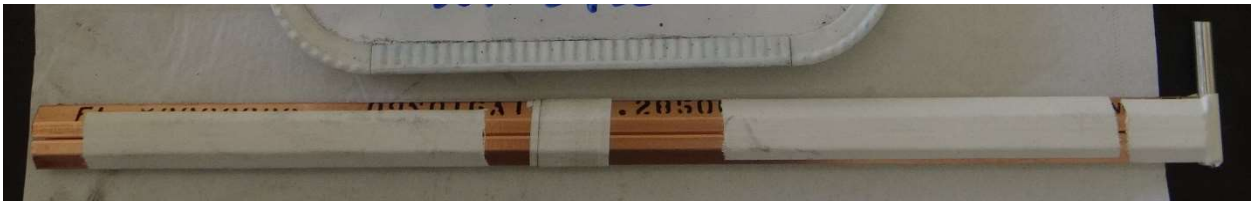


Photo 19: Sample ID #6A - Linear Shaped Charge, small (face-to-face)

5.10 Sample ID #5B/#6B - Linear Shaped Charge, medium

The article selected to represent this group was identified as P/N FL-Y2302000 Linear Shaped Charge manufactured by Accurate Energetic Systems, LLC at its McEwen, Tennessee facility. The product is constructed of a copper sheath material and contains 2000 gr/ft (10.8 grams/in) of RDX. The 2000-gr/ft Linear Shaped Charge had a width of 1.15 inches and length of 1.156 inches for a total of 12.5 grams each. The composition of the product is listed in the following table.

Table 10: Composition of the P/N FL-Y2302000 2000-gr/ft Linear Shaped Charge

Explosive Component	Constituents	Weight (%)	Explosive Weight
Core Material	Cyclotrimethylenetrinitramine (RDX)	92.5 - 99.3	2000 gr/ft @ 1.156 in
	Binder	0.7 - 5	
	Graphite	0 - 0.5	
	Calcium stearate	0 - 0.5	
		TOTAL	12.5 grams

Photo 20: P/N FL-Y2302000 2000-gr/ft Linear Shaped Charge

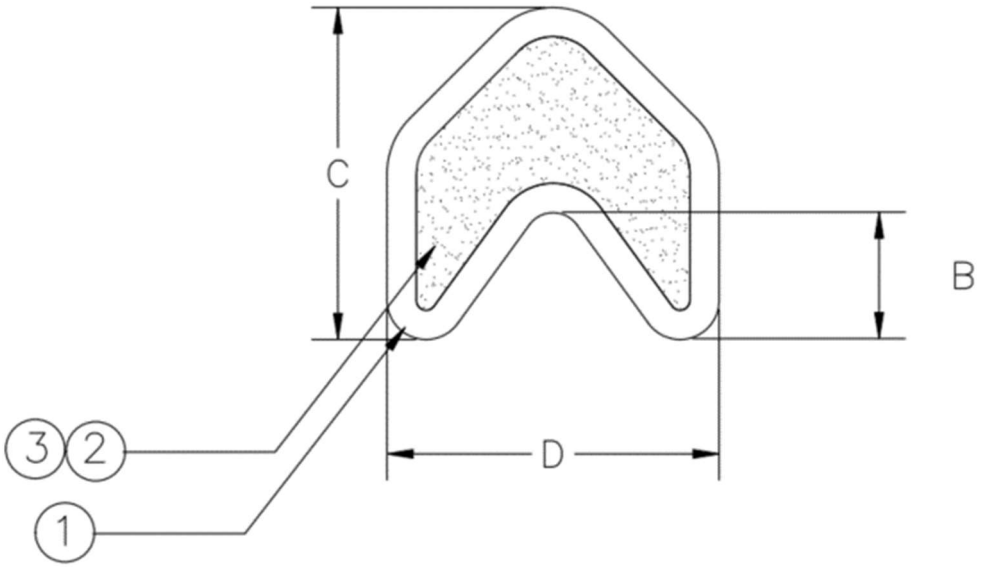


Figure 6: Drawing of the P/N FL-Y2302000 2000-gr/ft Linear Shaped Charge

The article was initiated by placing a detonator on one end, perpendicular to the linear shaped charge. For Sample ID #5B with detonator, three pieces were taped together in-line with each other (37.5grams), as shown in the following photo.

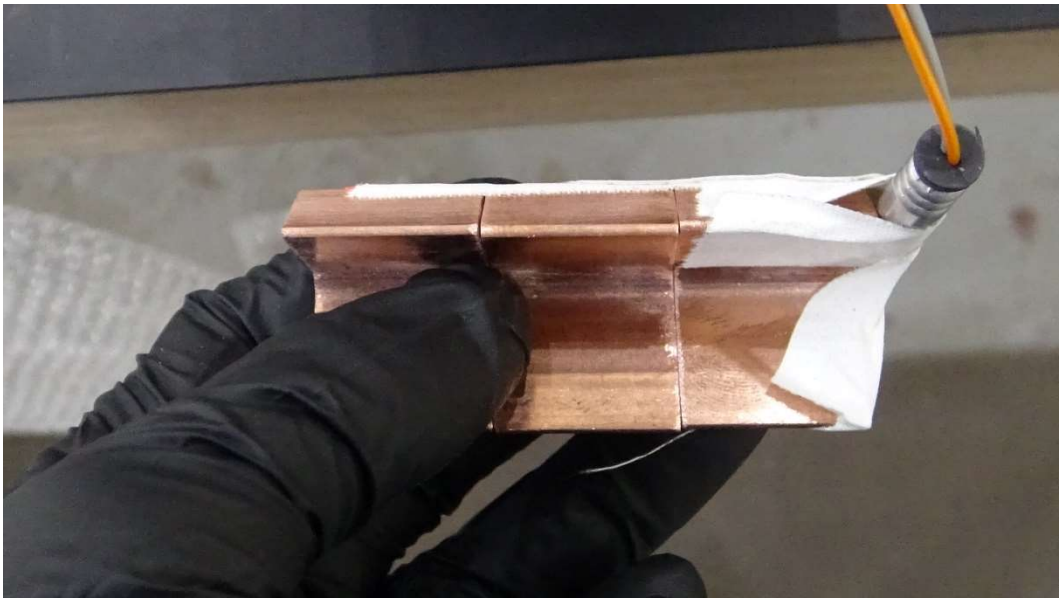


Photo 21: Sample ID #5B - Linear Shaped Charge, medium

There was insufficient product to perform testing on Sample ID #6B configured face-to-face.

5.11 Sample ID #5C/#6C - Linear Shaped Charge, large

The article selected to represent this group was identified as P/N FL-Y2304000 Linear Shaped Charge manufactured by Accurate Energetic Systems, LLC at its McEwen, Tennessee facility. The product is constructed of a copper sheath material and contains 4000 gr/ft (21.6 grains/in) of RDX. The 4000-gr/ft Linear Shaped Charge had a width of 1.55 inches and length of 1.156 inches for a total of 25 grams each. The composition of the product is listed in the following table.

Table 11: Composition of the P/N FL-Y2304000 4000-gr/ft Linear Shaped Charge

Explosive Component	Constituents	Weight (%)	Explosive Weight
Core Material	Cyclotrimethylenetrinitramine (RDX)	92.5 - 99.3	4000 gr/ft @ 1.156 in
	Binder	0.7 - 5	
	Graphite	0 - 0.5	
	Calcium stearate	0 - 0.5	
		TOTAL	25 grams

Photo 22: P/N FL-Y2304000 4000-gr/ft Linear Shaped Charge

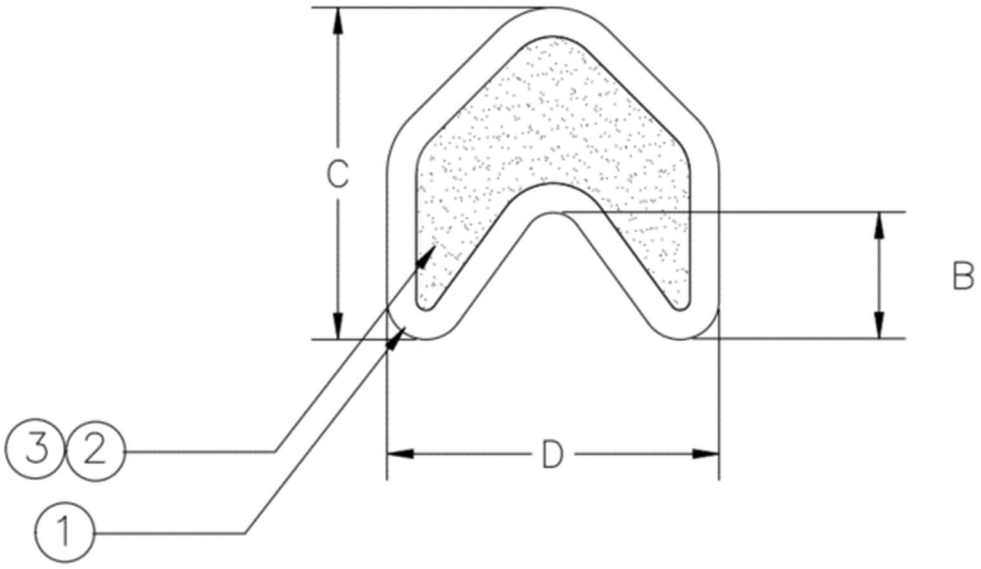


Figure 7: Drawing of the P/N FL-Y2304000 4000-gr/ft Linear Shaped Charge

The article was initiated by placing a detonator on one end, perpendicular to the linear shaped charge.

Photo 23: Sample ID #5C - Linear Shaped Charge, large

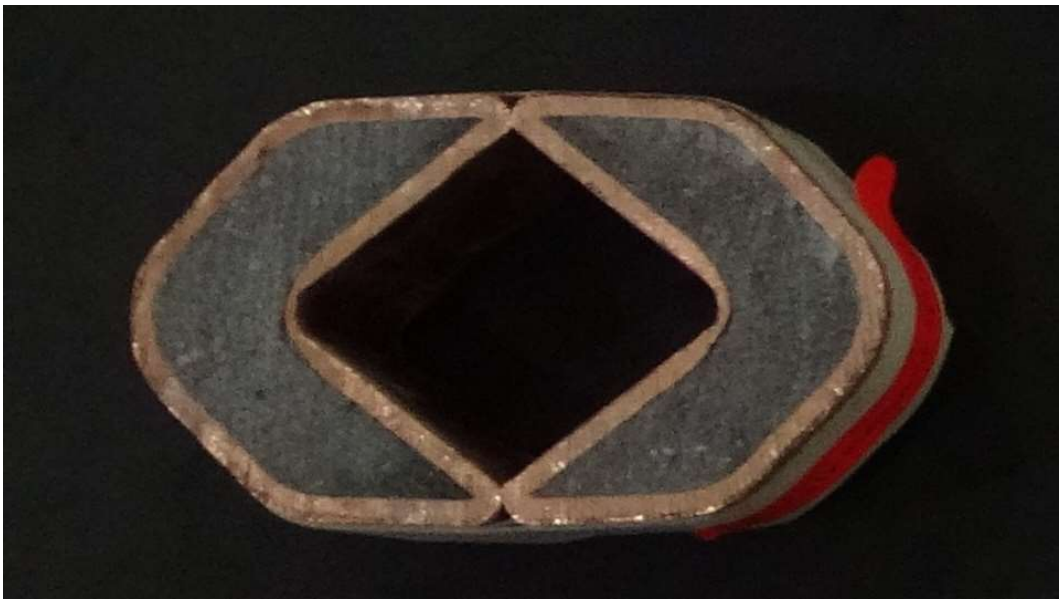


Photo 24: Sample ID #6C - Linear Shaped Charge, large (face-to-face)

5.12 Sample ID #5D/#6D - Linear Shaped Charge, X-large

The article selected to represent this group was identified as P/N FL-Y23010500 Linear Shaped Charge manufactured by Accurate Energetic Systems, LLC at its McEwen, Tennessee facility. The product is constructed of a copper sheath material and contains 10,500 gr/ft (56.7 grams/in) of RDX. The 10,500-gr/ft Linear Shaped Charge had a width of 2.23 inches and length of 0.444 inches for a total of 25.2 grams each. The composition of the product is listed in the following table.

Table 12: Composition of the P/N FL-Y23010500 10,500-gr/ft Linear Shaped Charge

Explosive Component	Constituents	Weight (%)	Explosive Weight
Core Material	Cyclotrimethylenetrinitramine (RDX)	92.5 - 99.3	10,500 gr/ft @ 0.444 in
	Binder	0.7 - 5	
	Graphite	0 - 0.5	
	Calcium stearate	0 - 0.5	
		TOTAL	25.2 grams

Photo 25: P/N FL-Y23010500 10,500-gr/ft Linear Shaped Charge

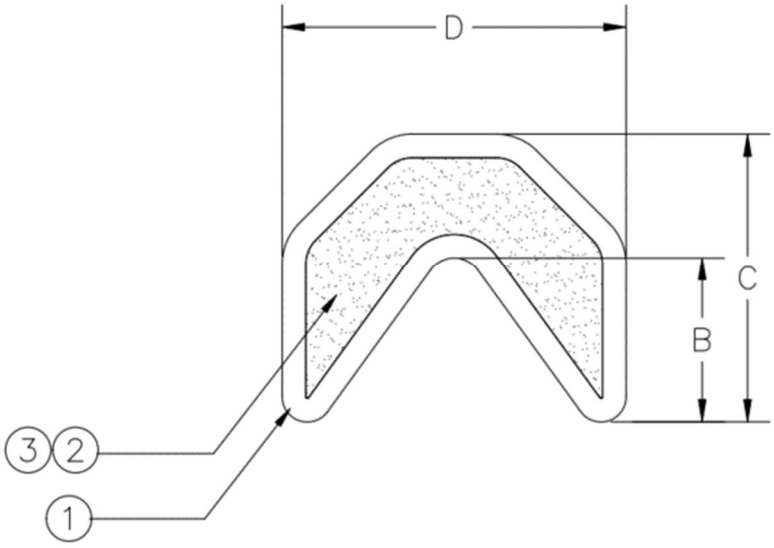


Figure 8: Drawing of the P/N FL-Y23010500 10,500-gr/ft Linear Shaped Charge

Photo 26: Sample ID #6D - Linear Shaped Charge, X-large (face-to-face)

5.13 Sample ID #7A/#8A/#17A - Conical Shaped Charge, small

The article selected to represent this group was identified as P/N EC1-15A0322, 1-9/16" 1503 RAZOR® XDP manufactured by GEODynamics at their Millsap, Texas facility. Each charge has a powdered metal liner (comprised of a mixture of tungsten, lead, and copper) and a zinc-plated steel casing. The product contains 3.2 grams of HMX.

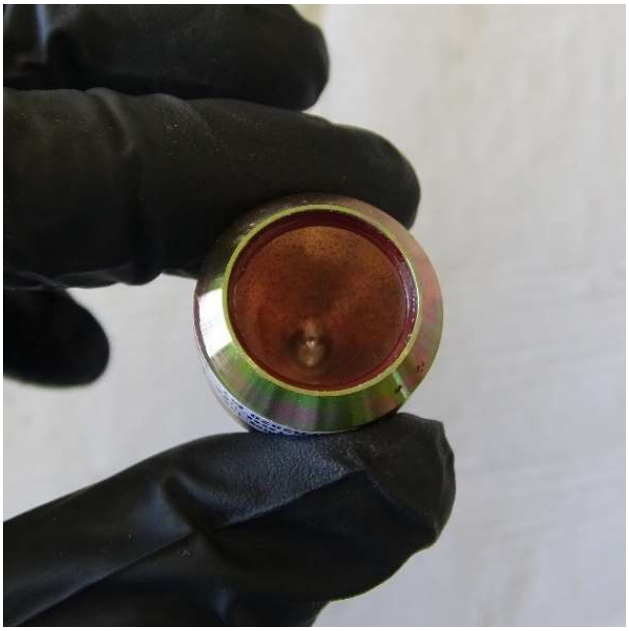


Photo 27: P/N EC1-15A0322, 1-9/16" GEOcmt XDP

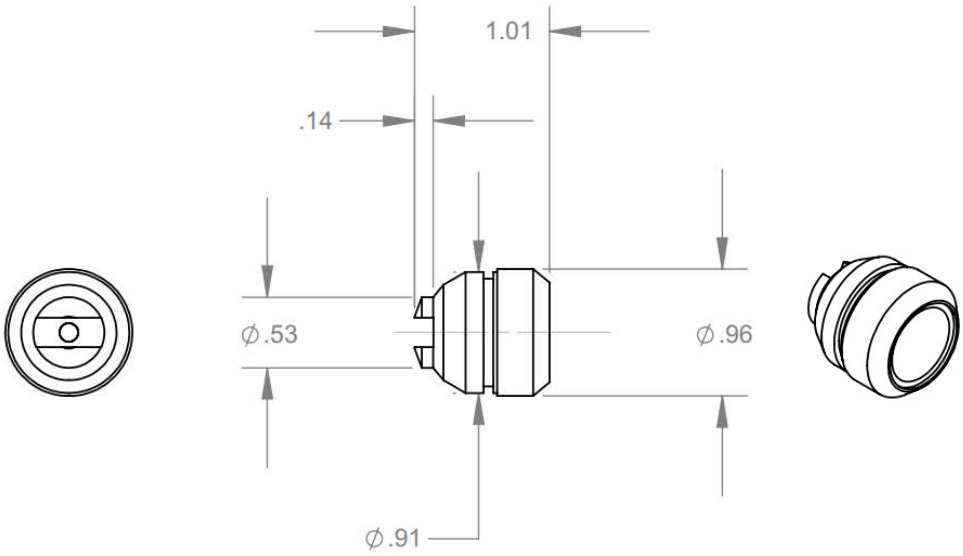


Figure 9: Drawing of the P/N EC1-15A0322, 1-9/16" RAZOR® XDP

Three configurations of shaped charges were evaluated: stacked facing end cap (Sample ID #7A, initiated on back end), face-to-face (Sample ID #8A, initiated in center), and interconnected using Fireline detonation cord & facing sideways (Sample ID #17A, initiated at one end of the detonation cord). Sample ID's #7A, #8A, and #17A utilized nine articles per trial (28.8 grams total), ten per trial (32.0 grams total), and eight articles per trial (25.6 grams total), respectively.

Photo 28: Sample ID #7A - Conical Shaped Charge, small, stacked face-to-end

Photo 29: Sample ID #8A - Conical Shaped Charge, small, configured face-to-face

Photo 30: Sample ID #17A - Conical Shaped Charge, small, interconnected with detonation cord & facing sideways

5.14 Sample ID #7B/#8B/#17B - Conical Shaped Charge, medium

The article selected to represent this group was identified as P/N EC2-23A1122, 2-3/8" 2311 RAZOR® XDP manufactured by GEODynamics at their Millsap, Texas facility. Each charge has a powdered metal liner (comprised of a mixture of tungsten, lead, and copper) and a zinc-plated steel casing. The product contains 11.0 grams of HMX.

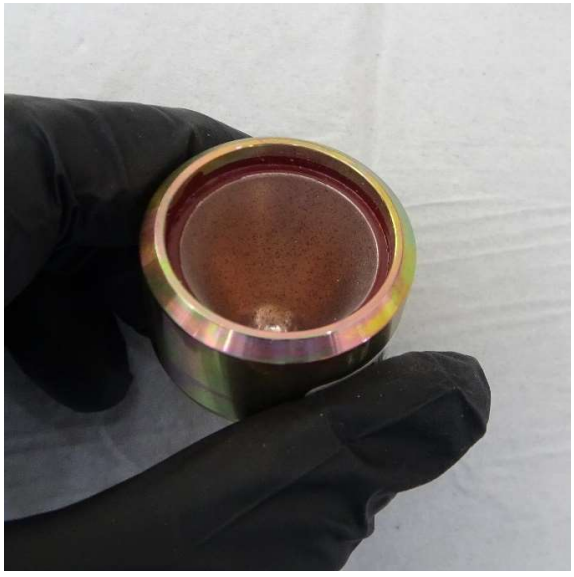


Photo 31: P/N EC2-23A1122, 2-3/8" 2311 RAZOR® XDP

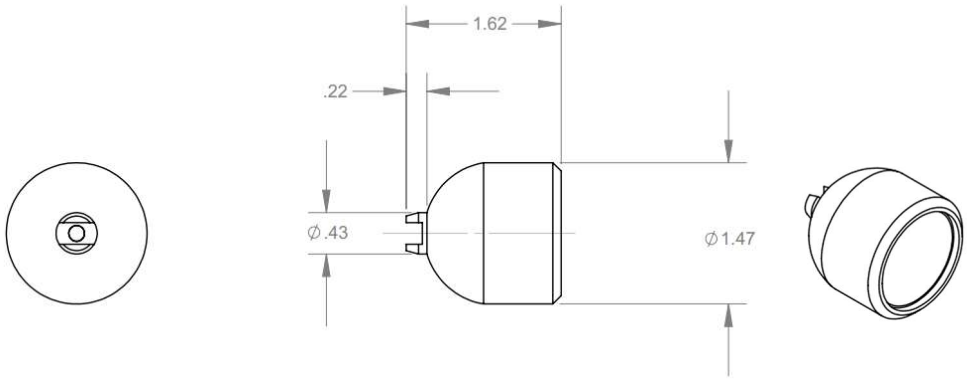


Figure 10: Drawing of the P/N EC2-23A1122, 2-3/8" 2311 RAZOR® XDP

Three configurations of shaped charges were evaluated: stacked facing end cap (Sample ID #7B, initiated on back end), face-to-face (Sample ID #8B, initiated in center), and interconnected using Fireline detonation cord & facing sideways (Sample ID #17B, initiated at one end of the detonation cord). Sample ID's #7B and #17B utilized three articles per trial (33.0 grams total), while #8B utilized four articles per trial (44.0 grams total).

Photo 32: Sample ID #7B - Conical Shaped Charge, medium, stacked face-to-end

Photo 33: Sample ID #8B - Conical Shaped Charge, medium, configured face-to-face

Photo 34: Sample ID #17B - Conical Shaped Charge, medium, interconnected with detonation cord & facing sideways

5.15 Sample ID #7C/#8C/#17C - Conical Shaped Charge, large

The article selected to represent this group was identified as P/N EC2-33B2522, 3-3/8" RAZOR® XDP manufactured by GEODynamics at their Millsap, Texas facility. Each charge is comprised of

an explosive pressed between has a metallic powder liner (comprised of a mixture of tungsten, lead, and copper) and a zinc-plated steel case. The product contains 25.0 grams of HMX.

Table 13: Composition of the P/N EC2-33B2522, 3-3/8" RAZOR® XDP

Explosive Component	Constituents	Weight (%)	Explosive Weight (g)
HMX Primer	HMX	99.8	
	RDX	0.2	
	Subtotal	100	1.0
HMX Main	HMX	98.0	
	Wax	1.5	
	Graphite	0.5	
	Subtotal	100	24.0
		TOTAL	25.0

Photo 35: P/N EC2-33B2522, 3-3/8" RAZOR® XDP

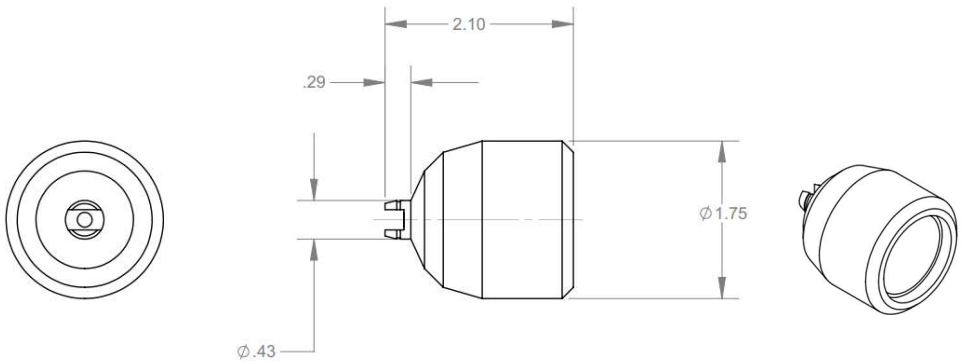


Figure 11: Drawing of the P/N EC2-33B2522, 3-3/8" RAZOR® XDP

Three configurations of shaped charges were evaluated: facing an end cap (Sample ID #7C, initiated on back end), face-to-face (Sample ID #8C, initiated at one back end), and facing sideways (Sample ID #17C, initiated on back end). Sample ID's #7C and #17C utilized one article per trial (25.0 grams total), while #8C utilized two articles per trial (50.0 grams total).

Photo 36: Sample ID #7C/#17C - Conical Shaped Charge, large

Photo 37: Sample ID #8C - Conical Shaped Charge, large, configured face-to-face

5.16 Sample ID #9A - Detonating Cord, small

The article selected to represent this group was identified as P/N A308033 Primacord 3. The item was manufactured by Dyno Nobel at its Graham, Kentucky facility. The detonating cord contains a nominal coreload of 15 gr/ft (3.2 g/m) of PETN and has an outer diameter of 0.14 inches. A length of 25.63 ft (25.0 grams) was utilized for this testing.

Photo 38: P/N A308033 Primacord 3 Detonating Cord

The article was initiated by placing a detonator on one end, parallel to the detonation cord.

Photo 39: Sample ID #9A - Detonating Cord, small

5.17 Sample ID #9B - Detonating Cord, medium

The article selected to represent this group was identified as P/N A571010 Fireline 17/80 HMX LS XHV detonating cord. The item was manufactured by Dyno Nobel at its Graham, Kentucky facility. The detonating cord contains a nominal coreload of 80 gr/ft (17 g/m) of HMX in a yellow/gold shrink-resistant braid in a green nylon jacket with a nominal outer diameter of 0.21 inches. A length of 4.82 ft (25.0 grams) was utilized for this testing.

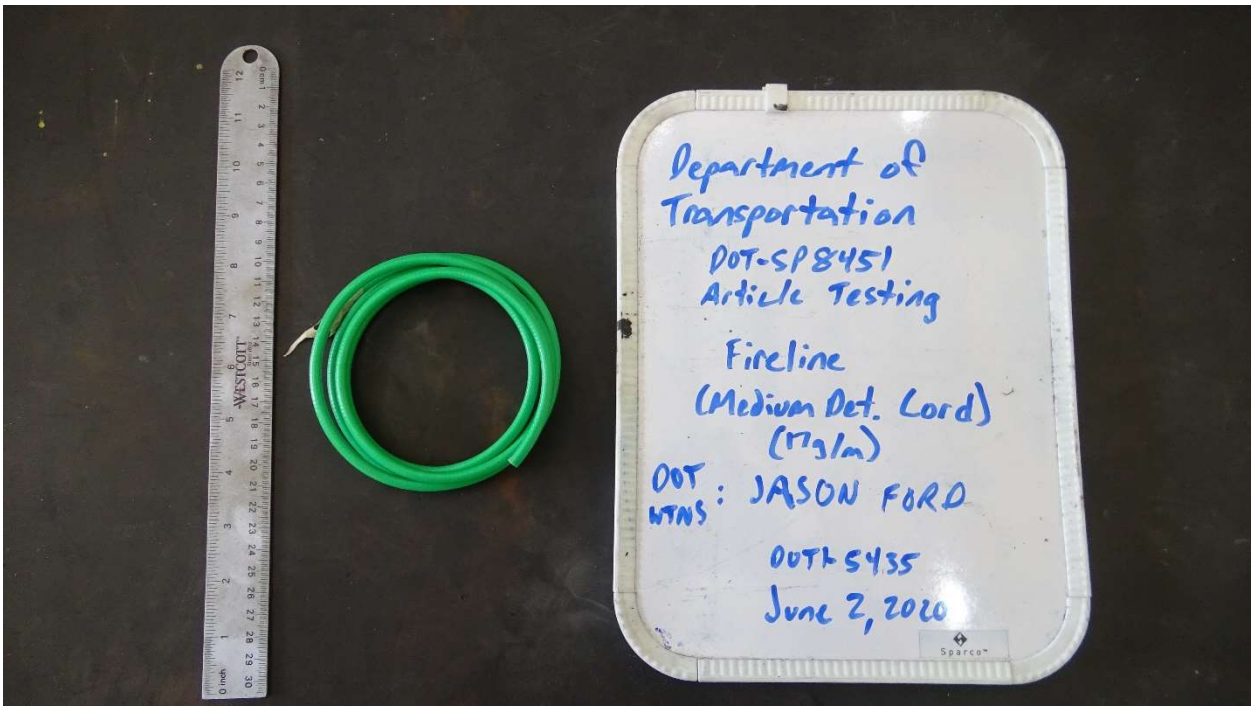


Photo 40: P/N A571010 Fireline 17/80 HMX LS XHV Detonating Cord

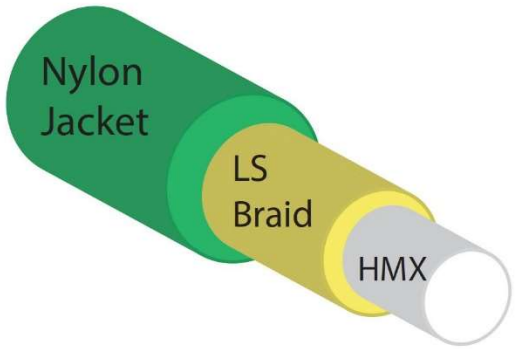


Figure 12: Drawing of the P/N A571010 Fireline 17/80 HMX LS XHV Detonating Cord

The article was initiated by placing a detonator on one end, parallel to the detonation cord.

Photo 41: Sample ID #9B - Detonating Cord, medium

5.18 Sample ID #10A1/#10A2 - Fragmenting Warhead/Bomblets, thin wall

The article representing this group was assembled by SMS from a 1-inch IPS x 2.25-inch long Schedule 40 steel pipe nipple (1.315-inch outer diameter, 0.113-inch thick walls) that contained two 1-inch diameter x 1-inch tall Composition A5 pellets (98.5 RDX and 1.5% stearic acid, density of 1.67 g/cm³, 22.9 grams N.E.W. each, 45.8 grams total). In initial trials, Sample ID #10A1 was terminated with a 1-inch diameter hardened M50 tool steel ball (explosively propelled); the steel ball was omitted in subsequent trials (Sample ID #10A2). The Composition A5 pellets were provided by Accurate Energetic Systems, LLC of McEwen, Tennessee.

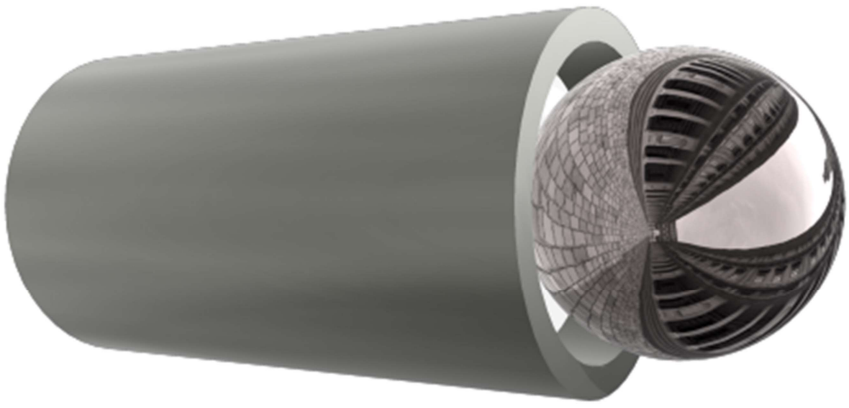


Figure 13: 3D Rendering of Sample ID #10A1 - Fragmenting Warhead/Bomblets, thin wall

5.19 Sample ID #10B - Fragmenting Warhead/Bomblets, medium wall

The article representing this group was assembled by SMS from a 1-1/4-inch IPS x 2.25-inch long Schedule 160 steel pipe nipple (1.66-inch outer diameter, 0.25-inch thick walls) that contained two 1-inch diameter x 1-inch tall Composition A5 pellets (98.5 RDX and 1.5% stearic acid, density of 1.67 g/cm^3, 22.9 grams N.E.W. each, 45.8 grams total). In initial trials, the article was terminated with a 1-inch diameter hardened M50 tool steel ball (explosively propelled); the steel ball was omitted in subsequent trials. The Composition A5 pellets were provided by Accurate Energetic Systems, LLC of McEwen, Tennessee.

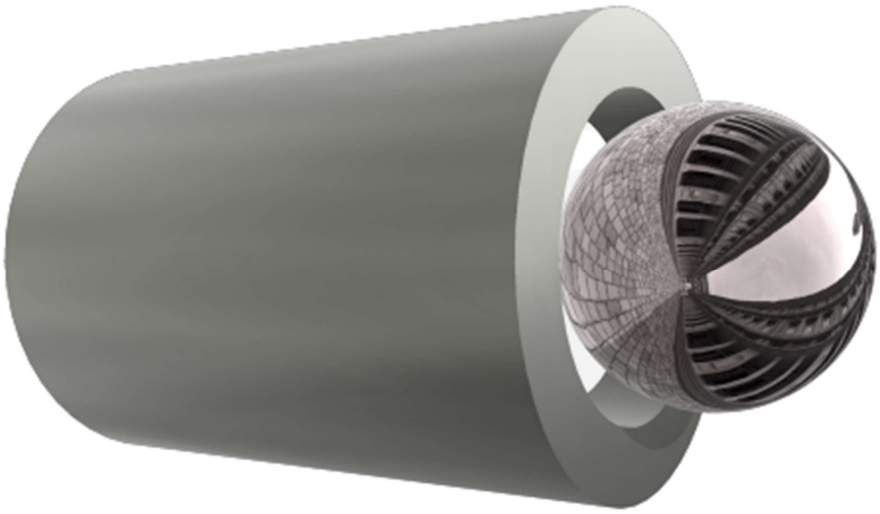


Figure 14: 3D Rendering of Sample ID #10B - Fragmenting Warhead/Bomblets, medium wall

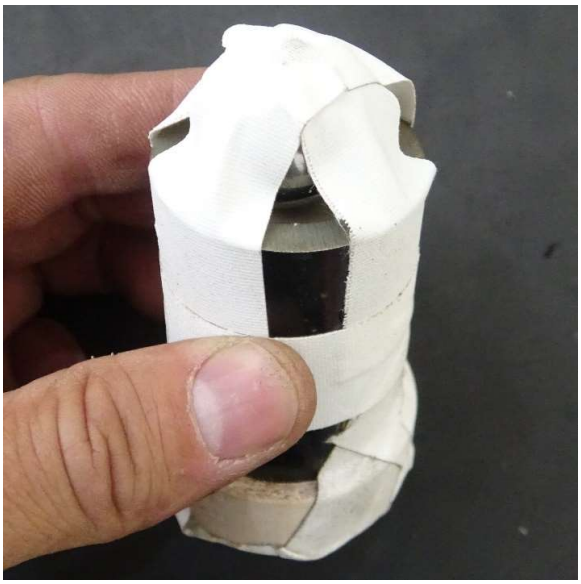


Photo 42: Sample ID #10B - Fragmenting Warhead/Bomblets, medium wall with detonator holder

5.20 Sample ID #10C - Fragmenting Warhead/Bomblets, thick wall

The article representing this group was assembled by SMS from a 1-1/2-inch IPS x 2.25-inch long Schedule XXH steel pipe nipple (1.9-inch outer diameter, 0.4-inch thick walls) that contained two 1-inch diameter x 1-inch tall Composition A5 pellets (98.5 RDX and 1.5% stearic acid, density of 1.67 g/cm³, 22.9 grams N.E.W. each, 45.8 grams total). In initial trials, the article was terminated with a 1-inch diameter hardened M50 tool steel ball (explosively propelled); the steel ball was omitted in subsequent trials. The Composition A5 pellets were provided by Accurate Energetic Systems, LLC of McEwen, Tennessee.

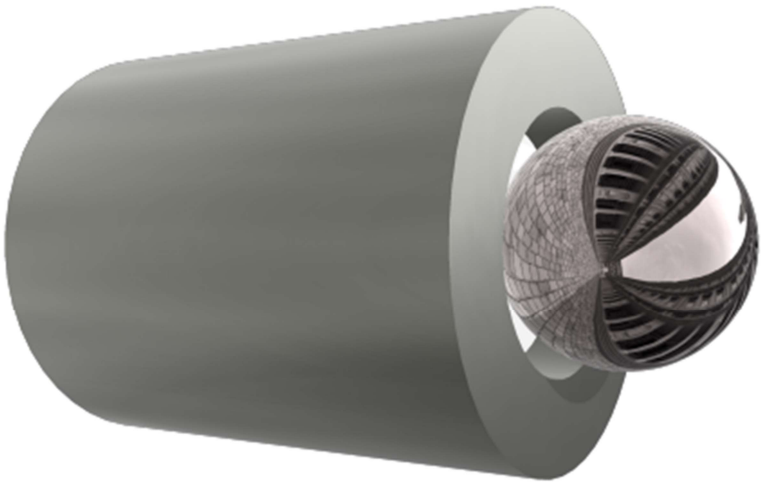


Figure 15: 3D Rendering of Sample ID #10C - Fragmenting Warhead/Bomblets, thick wall

5.21 Sample ID #11B1/#11B2 - Cannon with Armor Piercing Projectile, medium diameter

The article representing this group was a cannon assembled by SMS from a 3/4 NPT x 10-inch long Schedule XXH steel pipe nipple threaded on both ends and connected to a 2 x 3/4 NPT female straight reducer fitted with a 2 NPT plug. The reducer was filled with 25 grams (37 mL) of Accurate No. 2 Improved Smokeless Powder, an extremely fast burning, double-base, spherical handgun powder suitable for use in a wide range of handgun calibers and well suited for use in short barrel applications. A .50-Caliber armor piercing projectile was placed in a lubricated wad and muzzle loaded down the barrel; a .50-Caliber M2 armor piercing projectile (45.2 grams each of brass and steel) was utilized for Sample ID #11B1 and a .50-Caliber M903 Saboted Light Armor Penetrator (SLAP) from tungsten alloy (27.2 grams each of tungsten alloy) for Sample ID #11B2.

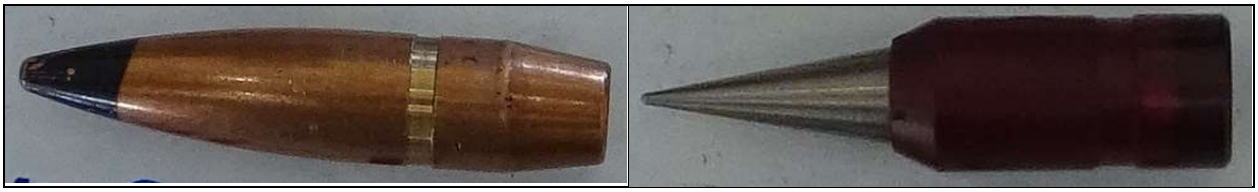


Photo 43: M2 Armor Piercing Projectile (left) and M903 SLAP Penetrator (right)

Photo 44: 2 x 3/4 NPT Female Straight Reducer: Exterior View of Plug with Match Leads (left), Interior View with Plug Removed (center), Electric Match in Plug (right)

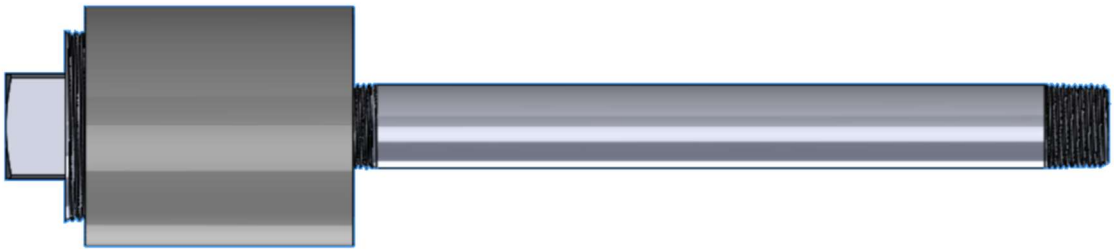


Figure 16: 2D Rendering of the Medium-diameter Cannon

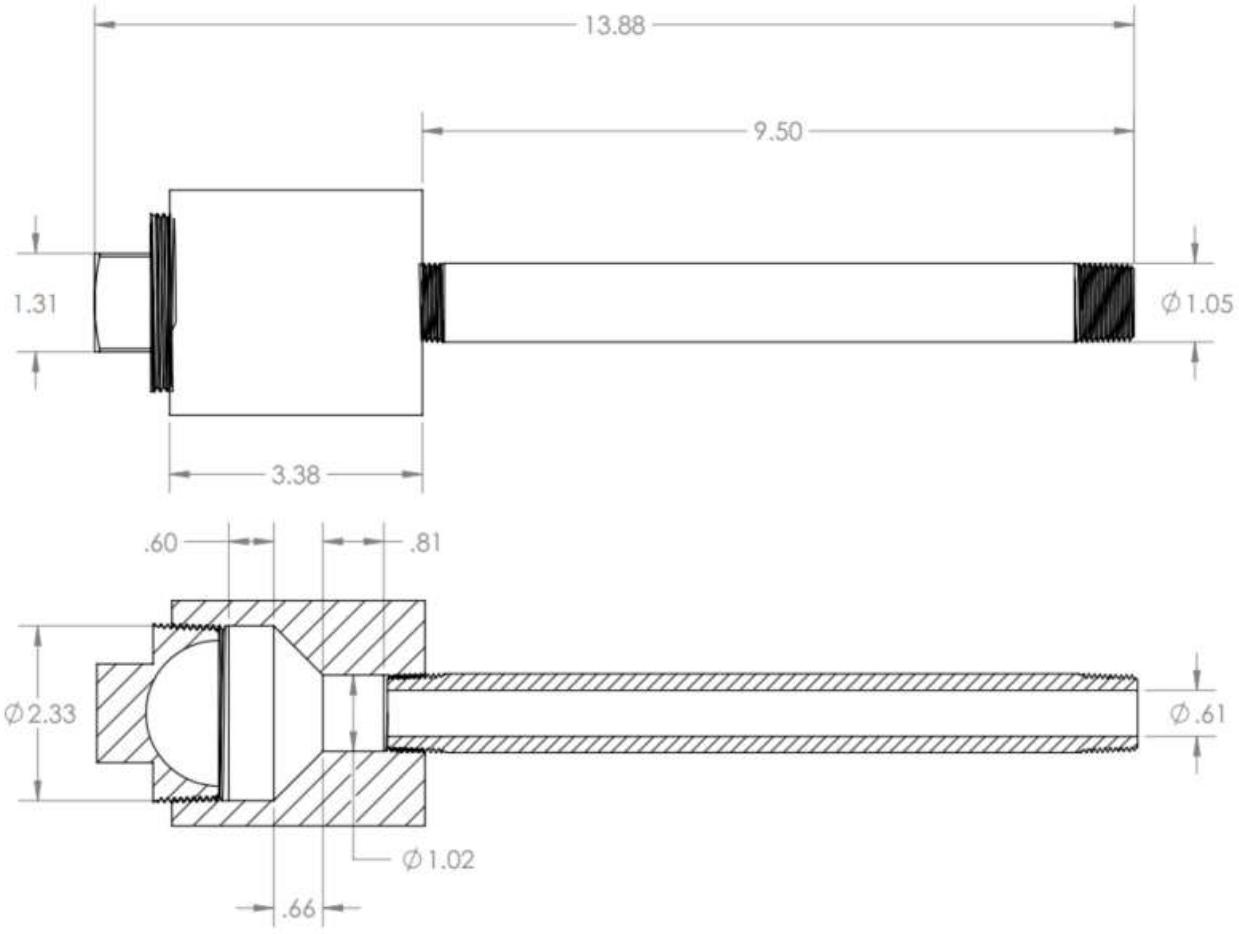


Figure 17: Drawing of the Medium-diameter Cannon

Photo 45: Accurate No. 2 Improved Smokeless Powder

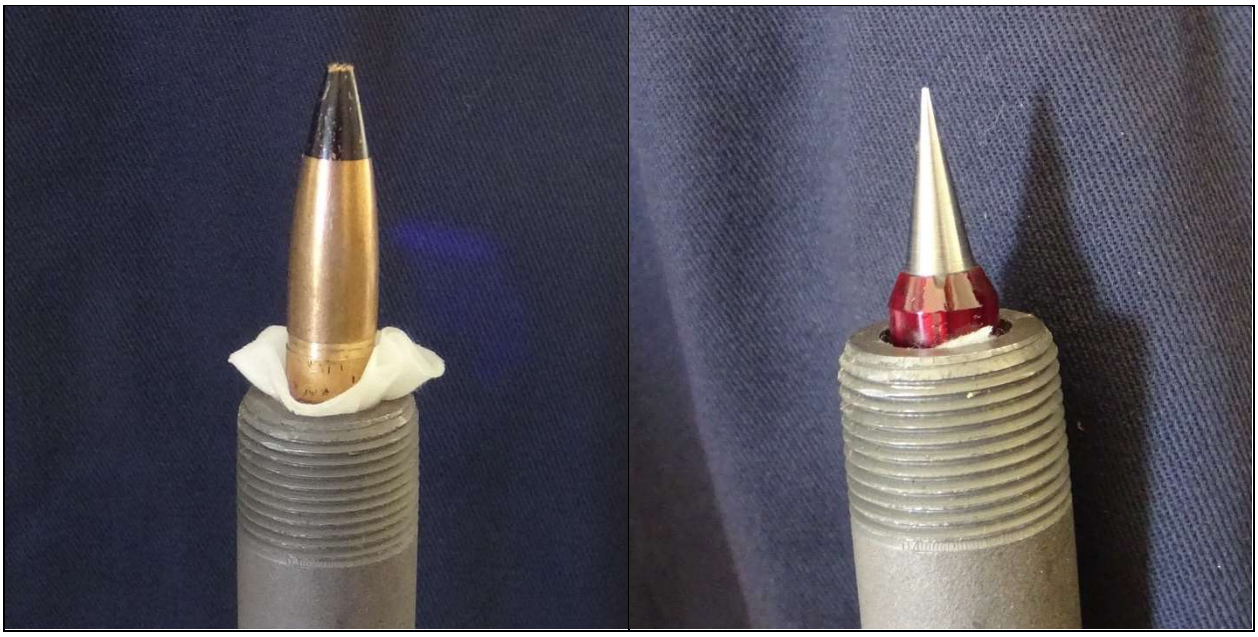


Photo 46: Muzzle-loading the M2 Armor Piercing Projectile (left) and M903 SLAP Penetrator (right)

5.22 Sample ID #12B - Ammunition Cartridge, medium with HEI projectile

The article selected to represent this group was identified as a P/N 12551767 20mm M940 Self Destruct Multi-Purpose Tracer cartridge containing 63 grams of WC866 propellant and 4.6 grams of Composition A-4. The item was manufactured by General Dynamics Ordnance and Tactical Systems at its Marion, Illinois facility. One article was used per trial.

Photo 47: P/N 12551767 20mm M940 Cartridge

Figure 18: Cross-section of the P/N 12551767 20mm M940 Cartridge

The cartridge's HEI projectile was initiated using a Trojan 20-gram Stinger booster.

Photo 48: Sample ID #12B - Ammunition Cartridge, medium with HEI projectile

5.23 Sample ID #13B1 - High Explosive Projectile (fragmenting), medium

The article selected to represent this group was identified as a P/N 12551768 20mm M940 Self Destruct Multi-Purpose Tracer projectile containing 4.6 grams of Composition A-4. The item

was manufactured by General Dynamics Ordnance and Tactical Systems at its Marion, Illinois facility.

Photo 49: P/N 12551768 20mm M940 Projectile

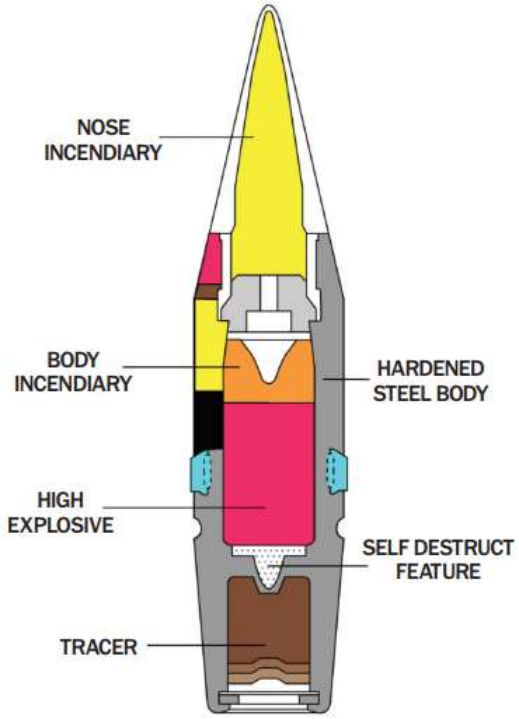


Figure 19: Cross-section of the P/N 12551768 20mm M940 Projectile

Seven projectiles were bundled together (32.2 grams net explosives weight) and initiated at the center of the cluster using a Trojan 20-gram Stinger booster.

Photo 50: Sample ID #13B1 - High Explosive Projectile, fragmenting, medium

5.24 Sample ID #13B2 - High Explosive Projectile, fragmenting, medium

The article selected to represent this group was identified as a P/N 1575AS601 20mm PGU-28A/B Semi-Armor Piercing (SAP) High Explosive Incendiary (HEI) projectile containing 4.6 grams of Composition A-4. The item was manufactured by General Dynamics Ordnance and Tactical Systems at its Marion, Illinois facility.

Photo 51: P/N 1575AS601 20mm PGU-28A/B SAPHEI Projectile

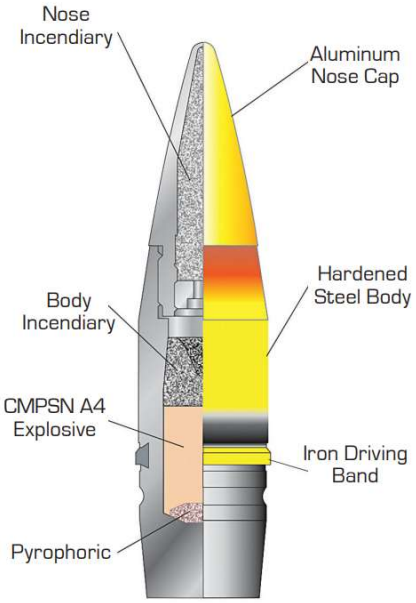


Figure 20: Cross-section of the P/N 1575AS601 20mm PGU-28A/B SAPHEI Projectile

Five projectiles were bundled together (23.0 grams net explosives weight) and initiated at the center of the cluster using a Trojan 20-gram Stinger booster.

Photo 52: Sample ID #13B2 - High Explosive Projectile, fragmenting, medium

5.25 Sample ID #13C - High Explosive Projectile, fragmenting, large

The article selected to represent this group was identified as a P/N 8100109-1ALG 30mm PGU-13D/B High Explosive Incendiary (HEI) projectile contains 48.0 grams of Composition A-4. The item was manufactured by General Dynamics Ordnance and Tactical Systems at its Marion, Illinois facility. One article was used per trial.

Photo 53: P/N 8100109-1ALG 30mm PGU-13D/B HEI Projectile

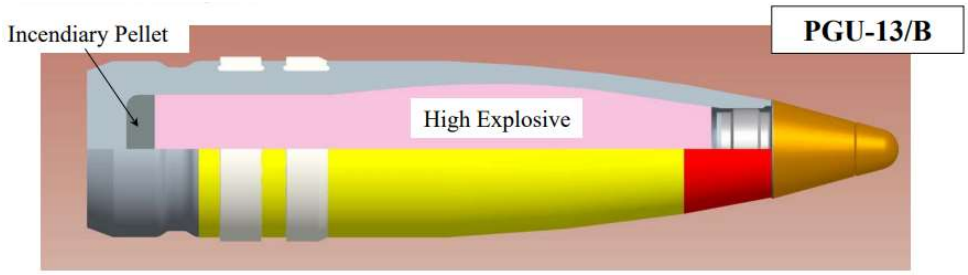


Figure 21: Cross-section of the P/N 8100109-1ALG 30mm PGU-13D/B HEI Projectile

The projectiles were initiated using a Trojan 20-gram Stinger booster.

Photo 54: Sample ID #13C - High Explosive Projectile, fragmenting, large

5.26 Sample ID #14B - Fuze, medium

The article selected to represent this group was identified as the P/N 41001023 F985 C fuze (also known as the 120mm IM HE-T Fuze) from lots SNE13D001-001 (19 each) and SNE16J006-001 (41 each). The item was manufactured by Nammo / SN Technolgoies SA at its Meyrin, Switzerland facility. The composition of the product is listed in the following table.

Table 14: Composition of the P/N 41001023 F985 C Fuze

Explosive Component	Constituents	Weight (%)	Explosive Weight (g)
Detonator	Lead azide	100	0.150
	PETN	100	0.035
	Subtotal	100	0.185
Delay detonator	Delay composition	100	0.025
	Lead azide	100	0.150
	PETN	100	0.035
	Subtotal	100	0.210
Lead charge	PBXN-5	100	0.130
Booster	PBXN-5	100	8.8
		TOTAL	9.325

Photo 55: P/N 41001023 F985 C Fuze

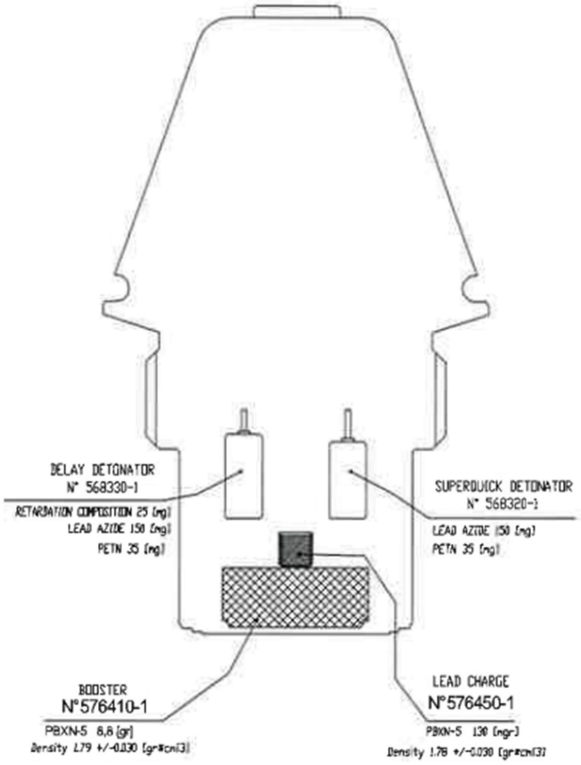


Figure 22: Drawing of the P/N 41001023 F985 C Fuze

For the external bonfire test, two fuzes were placed base-to-base and the remaining fuze was placed nose-to-nose with the center fuze (27.9 grams total).

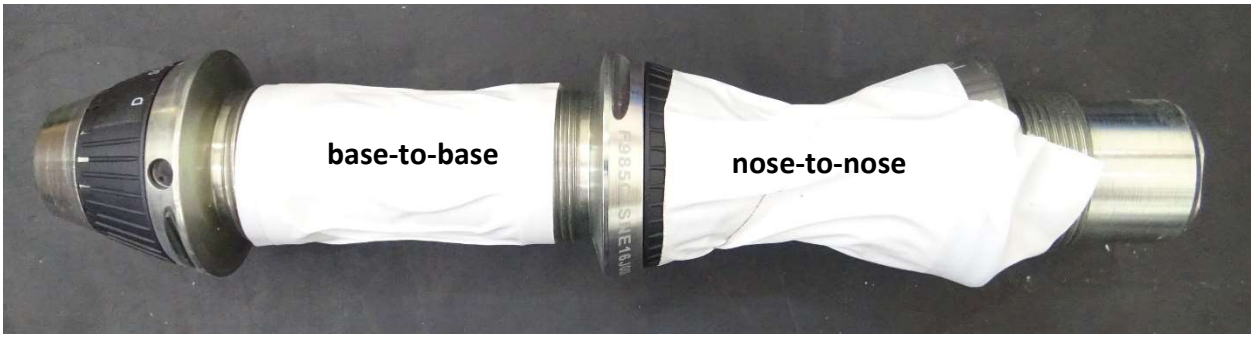


Photo 56: Sample ID #14B - Fuze, medium configured for Bonfire Test with Fuzes Base-to-Base (left) and with Fuzes Nose-to-Nose (right)

For the Unconfined package test, two fuzes were placed base-to-base and the remaining fuze was placed nose-to-base with the center fuze (27.9 grams total) and initiated at the center of the first cluster using a Trojan 20-gram Stinger booster.

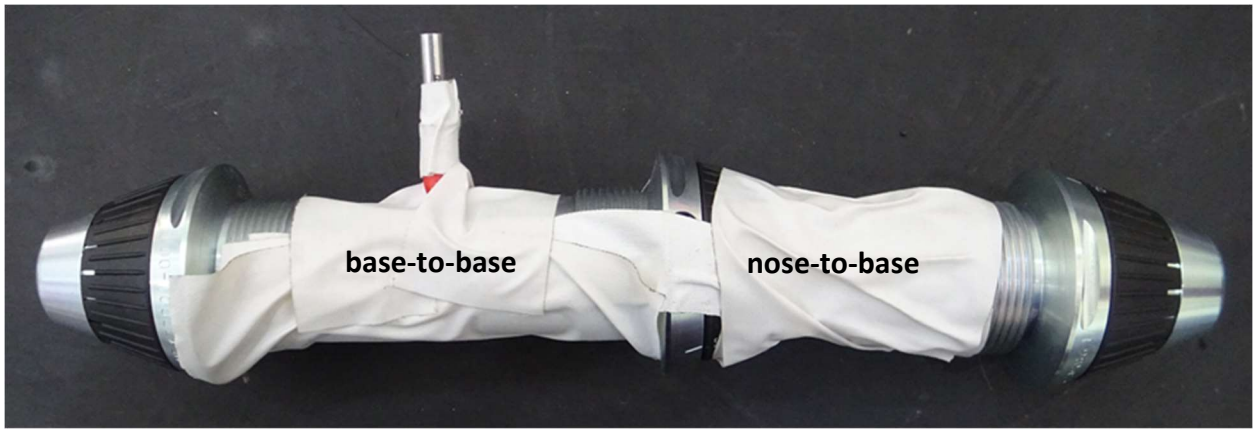


Photo 57: Sample ID #14B - Fuze, medium with detonation and 10-gram booster configured for Bonfire Test with Fuzes Base-to-Base (left) and with Fuzes Nose-to-Base (right)

5.27 Sample ID #15C - Rocket Motor, large

The article selected to represent this group was identified as a F32-4T 24 X 95mm Blue Thunder "E" Length composite model rocket motor (P/N 063204) that contains 25.8 grams of propellant with a burn time of 1.7 seconds, a total impulse of 56.9 Newton-seconds, and 61.3 Newtons of peak thrust. The item was manufactured by Aerotech Consumer Aerospace at its Cedar City, UT facility. The composition of the Blue Thunder propellant is proprietary (trade secret), but the Safety Data Sheet lists that it contains varying percentages of Ammonium Perchlorate, Strontium and/or Barium Nitrate dispersed in synthetic rubber with lesser amounts of proprietary ingredients such as burn rate modifiers and powdered metal fuels.

Photo 58: Rocket Motor, large

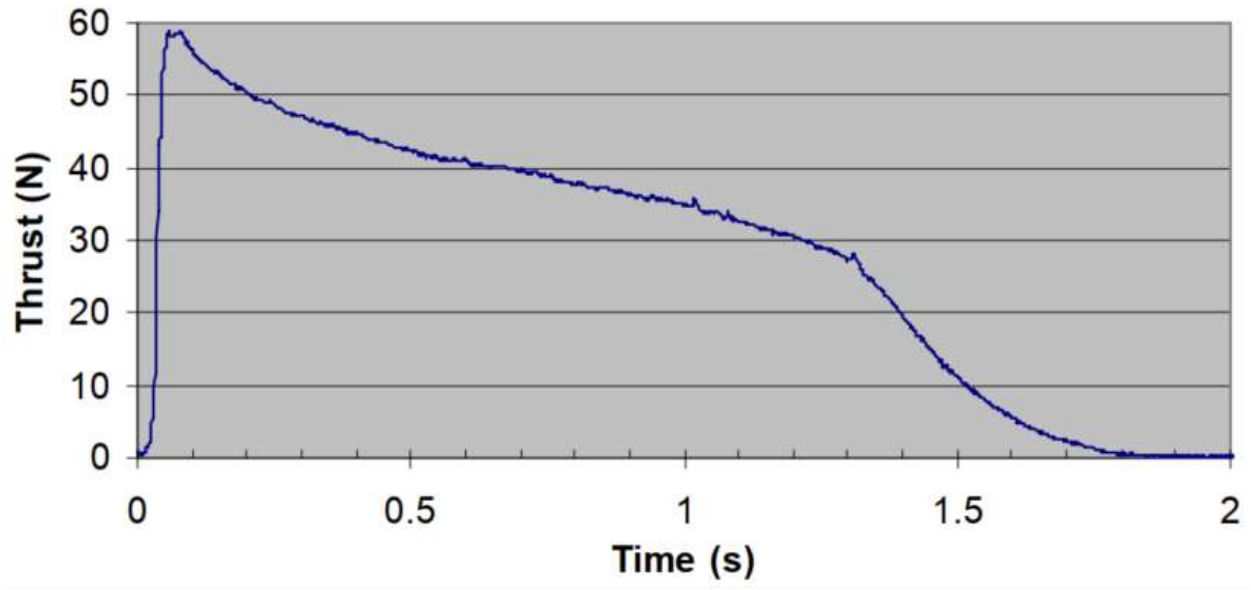


Figure 23: Typical Thrust-Time Plot for Aerotech F32-4T Blue Thunder Composite Model Rocket Motor

5.28 Sample ID #16C - Thermite Cutting Torch, large

The article selected to represent this group was identified as a custom thermite plate penetrator cartridge manufactured by Energetic Materials & Products Inc. at its Round Rock, Texas facility. The product was custom made for this testing as typical quantities of energetic material for these articles approach 100 grams. The provided articles contained approximately 50 grams of energetic material. The TEC Torch thermite formulation contains a proprietary blend of aluminum, magnesium, cupric oxide, and molybdenum oxide. The test article contained 3 - 6 grams of loose (tamped) charge, 44 - 47 grams of pressed charge, and an electric igniter.

Photo 59: Sample ID #16C - Thermite Cutting Torch, large

6.0 IDENTIFYING THE WORST-CASE TEST ARTICLES BY EFFECTS

6.1 Unpackaged UN Series 6 (d) Unconfined Package Test

6.1.1 *Test Description*

This test is performed to determine which articles produce worst-case blast effects when intentionally initiated within a DOT-SP 8451 containment pipe, as evidenced by the greatest pipe deformation and penetration/perforation.

A pre-determined quantity of the test item are arranged in a worst-case test configuration. The articles are caused to function if provided with their own means of initiation or caused to function using a suitable stimulus. The articles are positioned within the containment pipe by either 1) surrounding them with sufficient bubble wrap and centering within the containment pipe, or 2) taping them to the pipe's sidewall in the middle of the pipe). The containment pipe is closed with end caps that are screwed on a minimum of five threads by hand and then tightened with a wrench.

The unpackaged pipe is placed upon the ground and the circumfrence measured before and after the test at the top, middle, and bottom of the containment pipe. The explosive articles producing the greatest pipe deformation and penetration/perforation are designated as the worst-case test articles when intentionally initiated.

6.1.2 *Test Configuration*

A detonator containing 0.8 grams of PETN was utilized to initiate articles not provided with their own means of initiation. The leads were passed outside of the containment pipe using an end cap modified with two grub-style screws, electrically insulated from each other (similar to those utilized in the UN MTC, sixth revised edition, Appendix 7, HSL Flash Composition test).

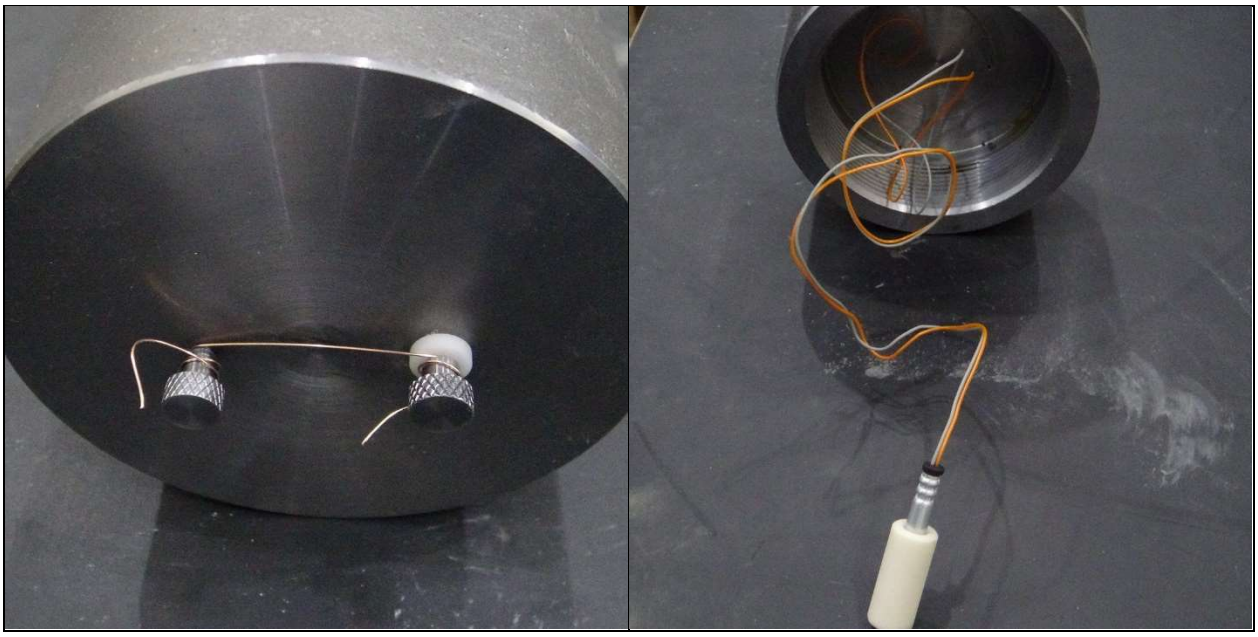


Photo 60: Shunted Bulkhead Connectors and Detonator (typical)

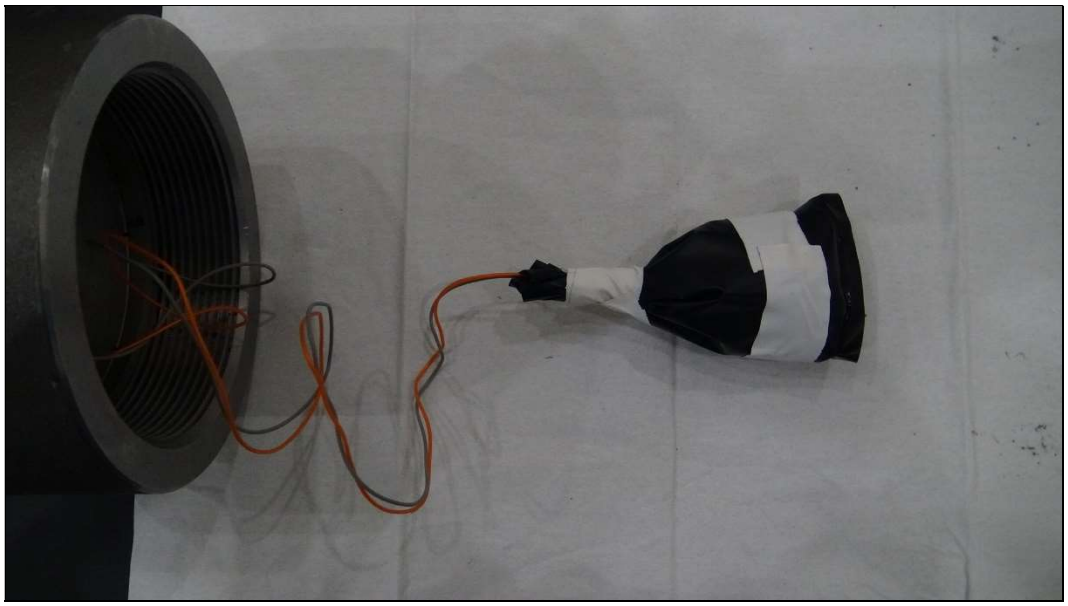


Photo 61: Detonator and Test Article without Means of Initiation (typical)

Photo 62: Unconfined Package Test Setup - Article Centered in Pipe using Bubble Wrap (typical)

Photo 63: Unconfined Package Test Setup - Article Contacting Sidewall (typical)

Photo 64: Unconfined Package Test Setup (typical)

The circumference before the test at the top, middle, and bottom measurement locations was 36.4 cm for each of the containment pipes.

6.1.3 *Test Results - Articles Centered in Containment Pipe*

Each article was successfully initiated in the center of a DOT-SP 8451, 4-inch diameter containment pipe, as summarized in the following table; also included is the post-test circumference at the top, middle, and bottom measurement locations.

Table 15: Unconfined Package Test Results (Article in Center)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	1B	30	36.4	**37.3**	36.4	Slightly visible bulge in center diameter; no perforation of pipe and no damage to end caps
2	1C	30	36.4	**36.8**	36.4	Slightly visible bulge in center diameter; no perforation of pipe and no damage to end caps
3	2B	27	36.4	**38.5**	36.4	Small perforation or crack in sidewall; pipe bulged surrounding perforation
4	3A	29.9	36.4	**36.7**	36.4	No damage to end caps, no visible bulge in center however measured slight bulge in center of pipe (cracked the paint)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
5	4C1	30.5	36.4	**38.3**	36.4	Small perforation or crack in sidewall; pipe bulged surrounding perforation
6	4C2	37.5	36.4	**38.8**	36.4	Visible bulge in center of pipe; no perforation of pipe and no damage to end caps
7	5A	25.0	**See results**	36.7	36.7	No damage to end caps, no visible bulge on pipe however measured slight bulge in center of pipe; the jet cut approximately one third of the way through the sidewall on the inside of the pipe
8	5B	37.5	**See results**	**See results**	**See results**	Approximately 5-inch × 4-inch hole in sidewall; approximately 3-inch × 3/4-inch hole in sidewall on opposite side
9	5C	25.0	36.4	**37.8**	36.4	Small perforation or crack observed in sidewall; bulge around perforation
10	5D	25.0	36.4	**37.5**	36.4	Visible bulge in center of pipe
11	6A	50.0	**36.8**	**36.8**	**36.8**	Slight crack observed near top of pipe into threads; no visible bulge
12	6B	50.0	n/a	n/a	n/a	*Insufficient product to perform test*
13	6C	50.0	**See results**	**See results**	**See results**	Pipe ruptured on both sides: 5-inch x 2-inch hole in one sidewall, 1-inch x 2.5-inch hole on opposite sidewall
14	6D	50.0	36.4	**38.0**	36.4	Visible bulge of the nipple; No perforations
15	7A	28.8	36.4	**36.9**	36.4	Very small hole in end cap; slight bulge in center of pipe
16	7B	33.0	36.4	36.4	**38.6**	Approximate 3/8-inch hole in bottom end cap; visible bulge evident on bottom portion of pipe
17	7C	25.0	**36.5**	**38.3**	36.4	Approximate 1/4-inch hole in bottom end cap, bulge visible in center of pipe
18	8A	32.0	36.4	**36.7**	**36.6**	No damage to end caps, no visible bulge on pipe however measured slight increase in center of pipe

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
19	8B	44.0	36.4	**36.8**	**38.5**	Small hole in bottom end cap; bulge visible on bottom portion of pipe
20	8C	50.0	36.4	36.4	**See results**	1/4-inch hole in bottom end cap; large hole (approximately 3-inch x 1.5-inch) on bottom half of pipe
21	9A	25.0	36.4	**36.5**	36.4	No visible damage to pipe or end caps
22	9B	25.0	36.4	**36.6**	36.4	Slightly visible bulge in center diameter; no perforation of pipe and no damage to end caps
23	10A1	45.8	36.4	**See results**	36.4	Pipe nipple severed in half
24	10A2	45.8	36.4	**See results**	36.4	Pipe nipple severed in half and petalled
25	10B	45.8	36.4	**See results**	36.4	Very large hole in center of pipe nipple (12 x 11 cm)
26	10C	45.8	36.4	**40.5**	36.4	Large bulge in center of pipe nipple; no perforation of pipe or end caps
27	11B1	25	36.4	36.4	36.4	No visible damage outside pipe; projectile was embedded into end cap
28	11B2	25	36.4	36.4	36.4	No visible damage to pipe or end caps
29	12B	^	36.4	**36.6**	36.4	No damage to end caps, no visible bulge on pipe however measured slight increase in center of pipe
30	13B1	32.2 (+ 20)	36.4	36.4	36.4	w/ booster: No visible damage to pipe or end caps
31	13B2	23.0 (+ 20)	36.4	**36.8**	36.4	w/ booster: No damage to end caps, no visible bulge on pipe however measured slight increase in center of pipe
32	13C	48.0 (+ 20)	36.4	**39.5**	36.4	w/ booster: Booster functioned but very minimal damage to PGU-13D/B projectile
33	14B	27.9 (+ 20)	36.4	36.4	36.4	w/ booster: No visible damage to pipe or end caps
34	15C	25.8	36.4	36.4	36.4	No visible damage to end caps or pipe

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
35	16C	50	36.4	36.4	36.4	No visible damage to pipe or end caps; sample consumed
36	17A	25.6	**36.7**	**36.7**	**36.7**	Eight small holes in sidewall of pipe (~0.8-cm diameter each); no visible damage to end caps
37	17B	33.0	36.4	**37.4**	36.4	Three medium holes in sidewall of pipe (~1.2-cm diameter each); no visible damage to end caps
38	17C	25.0	36.4	**37.7**	36.4	One large hole in sidewall of pipe (~1.9-cm diameter); no visible damage to end caps

^ Refer to military specifications.

The test results are shown in the following photos.

Photo 65: Unconfined Package Test Results (Article in Center) for Sample ID #1B - Booster (non-cased), (3) medium

Photo 66: Unconfined Package Test Results (Article in Center) for Sample ID #1C - Booster (non-cased), (1) medium and (1) large

Photo 67: Unconfined Package Test Results (Article in Center) for Sample ID #2B - Booster (metal cased), medium

Photo 68: Unconfined Package Test Results (Article in Center) for Sample ID #3A - Detonator, small

Photo 69: Unconfined Package Test Results (Article in Center) for Sample ID #4C1 - Grenade, fragmenting (pre-formed), large

Photo 70: Unconfined Package Test Results (Article in Center) for Sample ID #4C2 - Grenade, fragmenting (pre-formed), large

Photo 71: Unconfined Package Test Results (Article in Center) for Sample ID #5A - Linear Shaped Charge, small

Photo 72: Unconfined Package Test Results (Article in Center) for Sample ID #5B - Linear Shaped Charge, medium

Photo 73: Unconfined Package Test Results (Article in Center) for Sample ID #5C - Linear Shaped Charge, large

Photo 74: Unconfined Package Test Results (Article in Center) for Sample ID #5D - Linear Shaped Charge, X-large

Photo 75: Unconfined Package Test Results (Article in Center) for Sample ID #6A - Linear Shaped Charge, small (face-to-face)

Photo 76: Unconfined Package Test Results (Article in Center) for Sample ID #6C - Linear Shaped Charge, large (face-to-face)

Photo 77: Unconfined Package Test Results (Article in Center) for Sample ID #6D - Linear Shaped Charge, X-large (face-to-face)

Photo 78: Unconfined Package Test Results (Article in Center) for Sample ID #7A - Conical Shaped Charge, small (stacked face-to-end)

Photo 79: Unconfined Package Test Results (Article in Center) for Sample ID #7B - Conical Shaped Charge, medium (stacked face-to-end)

Photo 80: Unconfined Package Test Results (Article in Center) for Sample ID #7C - Conical Shaped Charge, large (single)

Photo 81: Unconfined Package Test Results (Article in Center) for Sample ID #8A - Conical Shaped Charge, small (face-to-face)

Photo 82: Unconfined Package Test Results (Article in Center) for Sample ID #8B - Conical Shaped Charge, medium (face-to-face)

Photo 83: Unconfined Package Test Results (Article in Center) for Sample ID #8C - Conical Shaped Charge, large (face-to-face)

Photo 84: Unconfined Package Test Results (Article in Center) for Sample ID #9A - Detonating Cord, small

Photo 85: Unconfined Package Test Results (Article in Center) for Sample ID #9B - Detonating Cord, medium

Photo 86: Unconfined Package Test Results (Article in Center) for Sample ID #10A1 - Fragmenting Warhead/Bomblets, thin wall

Photo 87: Unconfined Package Test Results (Article in Center) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball)

Photo 88: Unconfined Package Test Results (Article in Center) for Sample ID #10B - Fragmenting Warhead/Bomblets, medium wall

Photo 89: Unconfined Package Test Results (Article in Center) for Sample ID #10C - Fragmenting Warhead/Bomblets, thick wall

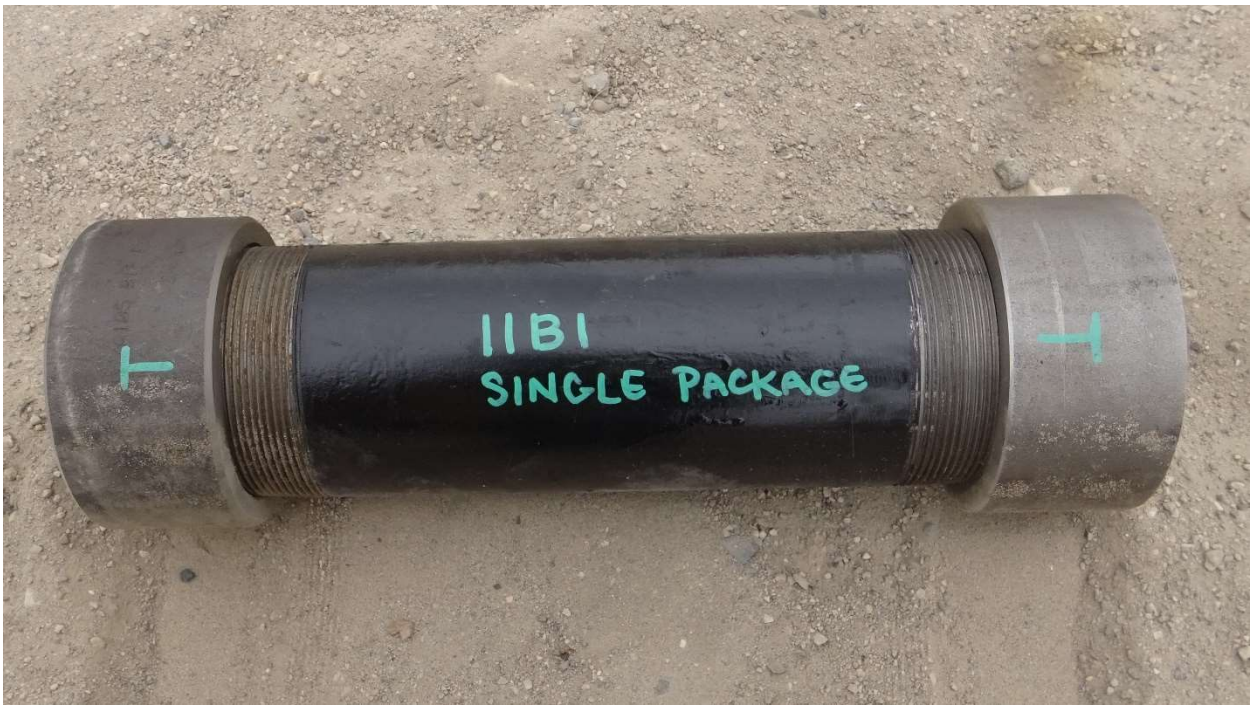


Photo 90: Unconfined Package Test Results (Article in Center) for Sample ID #11B1 - Cannon with Armor Piercing Projectile, medium diameter

Photo 91: Sample ID #11B1 - Post-Test View of Cannon Remains

Photo 92: Sample ID #11B1 - Partial Hole in End Cap by Armor Piercing Projectile

Photo 93: Unconfined Package Test Results (Article in Center) for Sample ID #11B2 - Cannon with Armor Piercing Projectile, medium diameter

Photo 94: Unconfined Package Test Results (Article in Center) for Sample ID #12B - Ammunition Cartridge, medium with HEI projectile

Photo 95: Unconfined Package Test Results (Article in Center) for Sample ID #13B1 - High Explosive Projectile, fragmenting, medium

Photo 96: Unconfined Package Test Results (Article in Center) for Sample ID #13B2 - High Explosive Projectile, fragmenting, medium

Photo 97: Unconfined Package Test Results (Article in Center) for Sample ID #13C - High Explosive Projectile, fragmenting, large

Photo 98: Unconfined Package Test Results (Article in Center) for Sample ID #14B - Fuze, medium

Photo 99: Unconfined Package Test Results (Article in Center) for Sample ID #15C - Rocket Motor, large

Photo 100: Unconfined Package Test Results (Article in Center) for Sample ID #16C - Thermite Cutting Torch, large

Photo 101: Unconfined Package Test Results (Article in Center) for Sample ID #17A - Conical Shaped Charge, small, interconnected & facing sideways

Photo 102: Unconfined Package Test Results (Article in Center) for Sample ID #17B - Conical Shaped Charge, medium, interconnected & facing sideways

Photo 103: Unconfined Package Test Results (Article in Center) for Sample ID #17C - Conical Shaped Charge, large, facing sideways

6.1.4 *Test Results - Article Contacting Sidewall of Containment Pipe*

Articles presenting the worst-case damage when centered within the DOT-SP 8451, 4-inch diameter containment pipe were then tested in contact with the sidewall of the pipe, as summarized in the following table; also included is the post-test circumference at the top, middle, and bottom measurement locations.

Table 16: Unconfined Package Test Results (Article Contacting Sidewall)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	2B	27	36.4	**See results**	36.4	Medium hole in sidewall (5 x 3 cm); no damage to end caps
2	4C2	37.5	36.4	**40.5**	36.4	Medium hole in sidewall (5 x 4 cm); no damage to end caps
3	5A	25.0	**See results**	**36.7**	**36.7**	Large split on top half of pipe approximately 4.5-inches long
4	5B	37.5	36.4	**See results**	36.4	6.4 x 2.5 cm hole in sidewall of pipe
5	6C	50.0	36.4	**See results**	36.4	Large hole in sidewall (9 x 10 cm); no damage to end caps
6	7C	25.0	36.4	**See results**	36.4	Tear in sidewall of pipe (2 x 4 cm); hole in end cap (0.5 cm diameter)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
7	10A2	45.8	36.4	**See results**	36.4	Large hole in sidewall (16 x 9 cm); no damage to end caps
8	13C	48.0 (+ 20)	36.4	**See results**	36.4	w/ booster: Large hole in sidewall (12 x 13 cm); no damage to end caps
9	17B	33.0	36.4	**37.5**	**36.5**	Three medium holes in sidewall of pipe (~1.5-cm diameter each); no visible damage to end caps

The test results are shown in the following photos.

Photo 104: Unconfined Package Test Results (Article Contacting Sidewall) for Sample ID #2B - Booster (metal cased), medium

Photo 105: Unconfined Package Test Results (Article Contacting Sidewall) for Sample ID #4C2 – Grenade, fragmenting (pre-formed), large

Photo 106: Unconfined Package Test Results (Article Contacting Sidewall) for Sample ID #5A - Linear Shaped Charge, small

Photo 107: Unconfined Package Test Results (Article Contacting Sidewall) for Sample ID #5B - Linear Shaped Charge, medium

Photo 108: Unconfined Package Test Results (Article Contacting Sidewall) for Sample ID #6C - Linear Shaped Charge, large (face-to-face)

Photo 109: Unconfined Package Test Results (Article Contacting Sidewall) for Sample ID #7C - Conical Shaped Charge, large (single)

Photo 110: Unconfined Package Test Results (Article Contacting Sidewall) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball)

Photo 111: Unconfined Package Test Results (Article Contacting Sidewall) for Sample ID #13C - High Explosive Projectile, fragmenting, large

Photo 112: Unconfined Package Test Results (Article Contacting Sidewall) for Sample ID #17B - Conical Shaped Charge, medium, interconnected & facing sideways

6.1.5 *Test Results - Articles in Containment Pipe with Perlite Blast Mitigation*

Each article was successfully initiated in the center of a DOT-SP 8451, 4-inch diameter containment pipe filled with perlite, as summarized in the following table; also included is the post-test circumference at the top, middle, and bottom measurement locations.

Table 17: Unconfined Package Test Results (Perlite Blast Mitigation)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	6C	50.0	36.4	**See Results**	36.4	Large hole in sidewall (7 x 7 cm); tear in sidewall of pipe (10 x 2 cm)
2	7C	25.0	36.4	**38.2**	36.4	Very small hole in end cap; small hole on threads below end cap; large bulge in center of pipe
3	8C	50.0	36.4	**39.4**	**38.3**	Large bulge in center diameter; no perforation of pipe and no damage to end caps
4	10A2	45.8	36.4	**See Results**	36.4	Large hole in sidewall; tears around the entire circumference of pipe
5	17B	33.0	36.4	**37.6**	36.4	Three small holes in sidewall of pipe; slight bulge in center of pipe

The test results are shown in the following photos.

Photo 113: Unconfined Package Test Results (Perlite Blast Mitigation) for Sample ID #6C - Linear Shaped Charge, large (face-to-face)

Photo 114: Unconfined Package Test Results (Perlite Blast Mitigation) for Sample ID #7C - Conical Shaped Charge, large (single)

Photo 115: Unconfined Package Test Results (Perlite Blast Mitigation) for Sample ID #8C - Conical Shaped Charge, large (face-to-face)

Photo 116: Unconfined Package Test Results (Perlite Blast Mitigation) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball)

Photo 117: Unconfined Package Test Results (Perlite Blast Mitigation) for Sample ID #17B - Conical Shaped Charge, medium (interconnected & facing sideways)

6.1.6 *Test Results - Articles in Containment Pipe with Metal-Sleeve Blast Mitigation*

Each article was successfully initiated in the center of a DOT-SP 8451, 4-inch diameter containment pipe lined with a metal sleeve, as summarized in the following table; also included is the post-test circumference at the top, middle, and bottom measurement locations.

Table 18: Unconfined Package Test Results (Metal-Sleeve Blast Mitigation)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	6C	50.0	36.4	36.4	**37.1**	Small bulge at bottom of pipe nipple
2	7C	25.0	36.4	**36.8**	36.4	No visible bulge in center however measured slight bulge in center of pipe; hole in end cap (1-cm diameter)
3	8C	50.0	36.4	36.4	**38.0**	Visible bulge on bottom of pipe
4	10A2	45.8	**See Results**	36.4	36.4	Rip on top of pipe nipple (12 x 8 cm)
5	17B	33.0	**37.0**	36.4	36.4	Three small holes in sidewall of pipe; no damage to end caps

The test results are shown in the following photos.

Photo 118: Unconfined Package Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #6C - Linear Shaped Charge, large (face-to-face)

Photo 119: Unconfined Package Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #7C - Conical Shaped Charge, large (single)

Photo 120: Unconfined Package Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #8C - Conical Shaped Charge, large (face-to-face)

Photo 121: Unconfined Package Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball)

Photo 122: Unconfined Package Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #17B - Conical Shaped Charge, medium (interconnected & facing sideways)

6.1.7 *Test Results - Articles in Containment Pipe with Rubber-Sleeve Blast Mitigation*

Each article was successfully initiated in the center of a DOT-SP 8451, 4-inch diameter containment pipe lined with a rubber-sleeve, as summarized in the following table.

Table 19: Unconfined Package Test Results (Rubber-Sleeve Blast Mitigation)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	6C	50.0	36.4	**36.8**	**41.1**	Large bulge in center of pipe nipple; no perforation of pipe or end caps
2	7C	25.0	36.4	36.4	**41.5**	End cap blown off pipe; pipe launched in air for ~2 seconds; large bulge on bottom of nipple threads; no perforation of pipe or end caps
3	8C	50.0	36.4	**36.8**	**40.0**	Large bulge in bottom of pipe nipple; no perforation of pipe or end caps
4	10A2	45.8	36.4	36.4	**38.5**	Small bulge at bottom of pipe; hole in end cap (~1 cm).
5	17B	33.0	36.4	**36.6**	**38.3**	Three holes (~1 cm) in sidewall of pipe; small bulge in bottom of pipe nipple

The test results are shown in the following photos.

Photo 123: Unconfined Package Test Results (Rubber-Sleeve Blast Mitigation) for Sample ID #6C - Linear Shaped Charge, large (face-to-face)

Photo 124: Unconfined Package Test Results (Rubber-Sleeve Blast Mitigation) for Sample ID #7C - Conical Shaped Charge, large (single)

Photo 125: Unconfined Package Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #8C - Conical Shaped Charge, large (face-to-face)

Photo 126: Unconfined Package Test Results (Rubber-Sleeve Blast Mitigation) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball)

Photo 127: Unconfined Package Test Results (Rubber-Sleeve Blast Mitigation) for Sample ID #17B - Conical Shaped Charge, medium (interconnected & facing sideways)

6.2 Unpackaged UN Series 6 (c) External Fire (Bonfire) Test

6.2.1 *Test Description*

This test is performed to determine which articles produce worst-case blast effects when subjected to a bonfire in a DOT-SP 8451 containment pipe, as evidenced by the greatest pipe deformation and penetration/perforation.

A pre-determined quantity of the test item are arranged in a worst-case test configuration. The articles are positioned within the containment pipe by either 1) surrounding them with sufficient bubble wrap and centering within the containment pipe, or 2) taping them to the pipe's sidewall in the middle of the pipe). The containment pipe is closed with end caps that are screwed on a minimum of five threads by hand and then tightened with a wrench.

The unpackaged pipe is placed on a non-combustible surface (steel grate) above a lattice of dried wood wetted with kerosene or diesel fuel; the pipes are secured to the steel grate. Sufficient wood is used to provide a 30-minute fire. Three witness screen frames are placed 4 meters from the edge of the stack as visible distance markers.

The circumfrence of the containment pipe is measured before and after the test at the top, middle, and bottom of the containment pipe. The explosive articles producing the greatest pipe deformation and penetration/perforation are designated as the worst-case test articles when in a bonfire.

6.2.2 *Test Configuration*

The test configuration is like that of the unpackaged UN Series 6 (d) Unconfined package test, except that the modified end caps and electric detonators were omitted. In some cases, M7 non-electric blasting caps were attached to the article to elicit a worst-case response; tests supplemented with detonators are designated in the results.

Table 20: External Fire Test Environmental Conditions

Fire	Wind Speed (m/s)	Temperature (°C)	% Relative Humidity
External Fire Test 1	3.1	19	26
External Fire Test 2	1.3	26	31
External Fire Test 3	3.1	34	13
External Fire Test 4	2.7	31	14
External Fire Test 5	1.8	25	22
External Fire Test 6	2.2	21	33
External Fire Test 7	1.8	26	18

Wire ties were utilized to secure the containment pipes to the steel grating to keep containers from rolling out of the fire (due to the force of gravity on an uneven surface created during test as pallet fuel is consumed and steel grate deforms), as allowed for in the UN Series 6 (c) test specification. It is noted that these wire ties do not affect the test results as the unpackaged UN Series 6 (d) demonstrated that there was no noticeable movement from reaction of the within the container, even when the product was initiated in contact with the sidewalls of the containment pipe; the wire ties would be expected to fail under application of any substanial force.

Photo 128: External Fire Test 1 Setup

Photo 129: External Fire Test 2 Setup

Photo 130: External Fire Test 3 Setup

Photo 131: External Fire Test 4 Setup

Photo 132: External Fire Test 5 Setup

Photo 133: External Fire Test 6 Setup

Photo 134: External Fire Test 7 Setup

6.2.3 *Test Results - Articles Centered in Containment Pipe*

The test results for each substance centered in the DOT-SP 8451, 4-inch diameter containment pipe in a bonfire are summarized in the following table. There were insufficient products supplied to perform tests for Sample ID's #5B without detonator and #6B with/without detonator.

****NOTE: The specific identity of the external bonfire pipes for Sample ID's #10A1, #10B, and #10C are in question since markings were obliterated and pipes were displaced from their original location; identities were assigned assuming test result consistency with that of the Single package test.****

Table 21: External Fire Test Results (Article in Center)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	1B	30	36.4	36.4	36.4	w/ detonator: No visible damage to pipe or end caps; sample consumed
2	1C	30	36.4	36.4	36.4	w/ detonator: No visible damage to pipe or end caps; sample consumed
3	2B	27	36.4	**37.8**	36.4	Large, visible bulge in sidewall of pipe
4	3A	29.9	36.4	**37.2**	36.4	Large bulge on one side of pipe

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
5	4C1	30.5	36.4	36.4	36.4	No visible damage to pipe or end caps; sample consumed
6	4C2	37.5	36.4	36.4	36.4	w/o detonator: No visible damage to pipe
7			36.4	**41.8**	36.4	w/ detonator: Large bulge/crack in center of pipe
8	5A	25.0	**37.9**	37.7	37.5	w/o detonator: Sample consumed; perforation/crack in pipe in top threads
9			**38.0**	37.0	36.8	w/ detonator: Visible deformation from LSC along the entire length of the nipple; breech of 6.5 cm at the top thread
10	5B	37.5	**See results**	36.4	36.4	w/ detonator: End cap blown off landing approximately 21 yards away; two holes (one large, one small) in top of pipe
11	5C	25.0	36.4	**36.5**	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
12			36.4	**37.0**	36.4	w/ detonator: Two perforations in the center of pipe (large hole 4x2 cm, small hole 1x3 cm)
13	5D	25.0	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
14			36.4	**39.5**	36.4	w/ detonator: Large bulge in center of pipe; small crack in bulge
15	6A	50.0	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
16			36.7	**38.0**	36.8	w/ detonator: Bulge along entire length of pipe
17	6C	50.0	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
18			36.4	36.4	36.4	w/ detonator: No visible damage to pipe or end caps; sample consumed
19	6D	50.0	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
20			36.4	36.4	36.4	w/ detonator: No visible damage to pipe or end caps; sample consumed
21	7A	28.8	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
22			36.5	**38.0**	38.0	w/ detonator: Visible large bulge on bottom of nipple and cap bulged slightly at threads
23	7B	33.0	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
24			36.4	**42.0**	36.5	w/ detonator: Very large bulge in center of pipe, slight crack in center of bulge (~1 cm)
25	7C	25.0	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
26			37.0	**42.7**	36.5	w/ detonator: Large bulge at center of pipe; perforation at largest portion of bulge (1 x 3 cm slit)
27	8A	32.0	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
28			36.4	**37.0**	36.4	w/ detonator: Small bulge in center of pipe; no perforations
29	8B	44.0	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
30			36.4	**38.5**	36.4	w/ detonator: Visible bulge in center of pipe; no perforations
31	8C	50.0	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
32			36.4	36.4	**37.0**	w/ detonator: Hole in end cap (3-cm diameter); small bulge visible in lower portion of pipe nipple
33	9A	25.0	36.4	**36.5**	36.4	w/ detonator: No visible damage to pipe or end caps; sample consumed
34	9B	25.0	36.4	**36.8**	36.4	w/ detonator: Slight bulge in center diameter of pipe

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
35	10A1	45.8	36.4	**See results**	36.4	w/ detonator: Large hole in center of pipe (11x10cm); large bulge
36	10A2	45.8	**39.0**	36.4	36.4	w/ detonator: End cap blown off; top of pipe nipple shredded and ripped apart
37			36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps
38	10B	45.8	37.0	**See results**	36.4	w/ detonator & hardened ball: Bulge in upper third of pipe nipple; perforation in nipple (4 x 4 cm)
39	10C	45.8	**39.9**	36.4	36.4	w/ detonator & hardened ball: End cap blown off, no perforations in pipe; big bulging of pipe threads
40	11B1	25	36.4	36.4	36.4	No visible damage
41	11B2	25	36.4	36.4	36.4	No visible damage
42	12B	^	36.4	36.4	36.4	No visible damage to pipe or end caps
43	13B1	32.2 (+ 20)	36.4	**36.7**	36.4	w/ detonator & booster: Very small bulge in center of pipe; no perforations
44	13B2	23.0 (+ 20)	**37.2**	36.4	36.4	w/ detonator & booster: Small bulge in center of pipe; no perforations
45	13C	48.0 (+ 20)	36.4	**37.0**	36.4	w/ detonator & booster: Small bulge in center of pipe; no perforations; no damage to end caps
46	14B	27.9	36.4	36.4	36.4	w/o detonator: No visible damage to pipe or end caps; sample consumed
47		27.9 (+ 20)	36.4	**39.0**	36.4	w/ detonator & booster: Large bulge in the center of the pipe nipple; no perforation and no damage to end caps
48	15C	25.8	36.4	36.4	36.4	No visible damage to pipe or end caps; sample consumed
49	16C	50	36.4	36.4	36.4	No visible damage to pipe or end caps; sample consumed
50	17A	25.6	36.4	**37.5**	37.5	w/ detonator: Eight small holes in sidewall of pipe (~1-cm diameter each); no visible damage to end caps

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
51	17B	33.0	**39.5**	36.5	36.4	w/ detonator: Three medium holes in sidewall of pipe (~1.5-cm diameter each); no visible damage to end caps
52	17C	25.0	**39.0**	36.4	36.4	w/ detonator: One hole in end cap (~1-cm diameter); top of pipe threads bulged (conical charge must have shifted from original position)

*Refer to military specifications

The test results are shown in the following photos.

Photo 135: External Fire Test Results (Article in Center) for Sample ID #1B - Booster (non-cased), (3) medium with detonator

Photo 136: External Fire Test Results (Article in Center) for Sample ID #1C - Booster (non-cased), (1) large & (1) medium with detonator

Photo 137: External Fire Test Results (Article in Center) for Sample ID #2B - Booster (metal cased), medium

Photo 138: External Fire Test Results (Article in Center) for Sample ID #3A - Detonator, small

Photo 139: External Fire Test Results (Article in Center) for Sample ID #4C1 - Grenade, fragmenting (pre-formed), large

Photo 140: External Fire Test Results (Article in Center) for Sample ID #4C2 - Grenade, fragmenting (pre-formed), large without detonator

Photo 141: External Fire Test Results (Article in Center) for Sample ID #4C2 - Grenade, fragmenting (pre-formed), large with detonator

Photo 142: External Fire Test Results (Article in Center) for Sample ID #5A - Linear Shaped Charge, small without detonator

Photo 143: External Fire Test Results (Article in Center) for Sample ID #5A - Linear Shaped Charge, small with detonator

Photo 144: External Fire Test Results (Article in Center) for Sample ID #5B - Linear Shaped Charge, medium with detonator

Photo 145: External Fire Test Results (Article in Center) for Sample ID #5C - Linear Shaped Charge, large without detonator

Photo 146: External Fire Test Results (Article in Center) for Sample ID #5C - Linear Shaped Charge, large with detonator

Photo 147: External Fire Test Results (Article in Center) for Sample ID #5D - Linear Shaped Charge, X-large without detonator

Photo 148: External Fire Test Results (Article in Center) for Sample ID #5D - Linear Shaped Charge, X-large with detonator

Photo 149: External Fire Test Results (Article in Center) for Sample ID #6A - Linear Shaped Charge, small (face-to-face) without detonator

Photo 150: External Fire Test Results (Article in Center) for Sample ID #6A - Linear Shaped Charge, small (face-to-face) with detonator

Photo 151: External Fire Test Results (Article in Center) for Sample ID #6C - Linear Shaped Charge, large (face-to-face) without detonator

Photo 152: External Fire Test Results (Article in Center) for Sample ID #6C - Linear Shaped Charge, large (face-to-face) with detonator

Photo 153: External Fire Test Results (Article in Center) for Sample ID #6D - Linear Shaped Charge, X-large (face-to-face) without detonator

Photo 154: External Fire Test Results (Article in Center) for Sample ID #6D - Linear Shaped Charge, X-large (face-to-face) with detonator

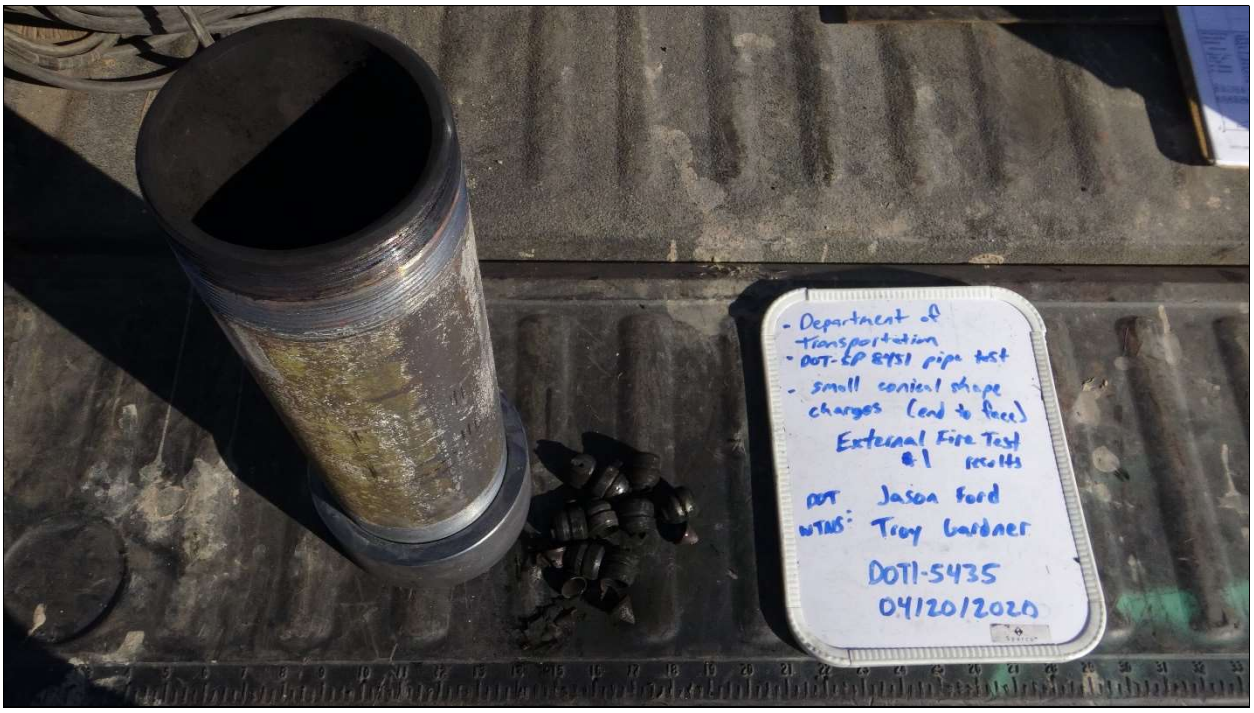


Photo 155: External Fire Test Results (Article in Center) for Sample ID #7A - Conical Shaped Charge, small (stacked face-to-end) without detonator

Photo 156: External Fire Test Results (Article in Center) for Sample ID #7A - Conical Shaped Charge, small (stacked face-to-end) with detonator

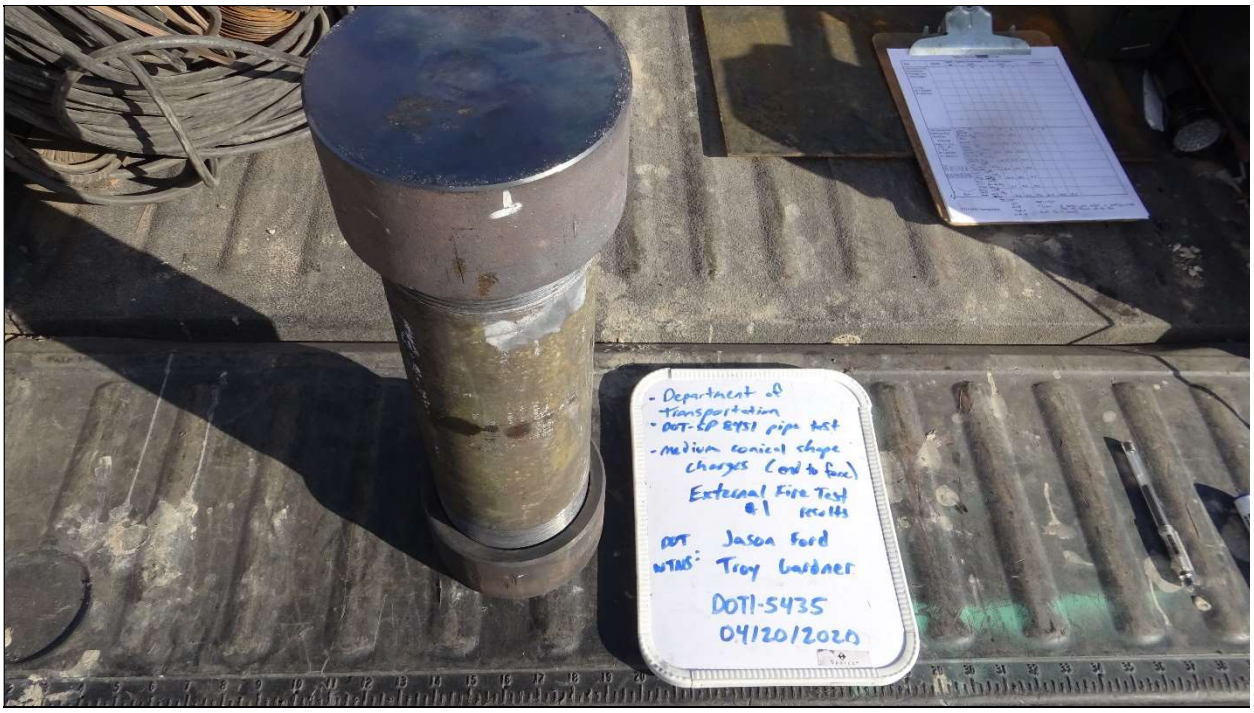


Photo 157: External Fire Test Results (Article in Center) for Sample ID #7B - Conical Shaped Charge, medium (stacked face-to-end) without detonator

Photo 158: External Fire Test Results (Article in Center) for Sample ID #7B - Conical Shaped Charge, medium (stacked face-to-end) with detonator

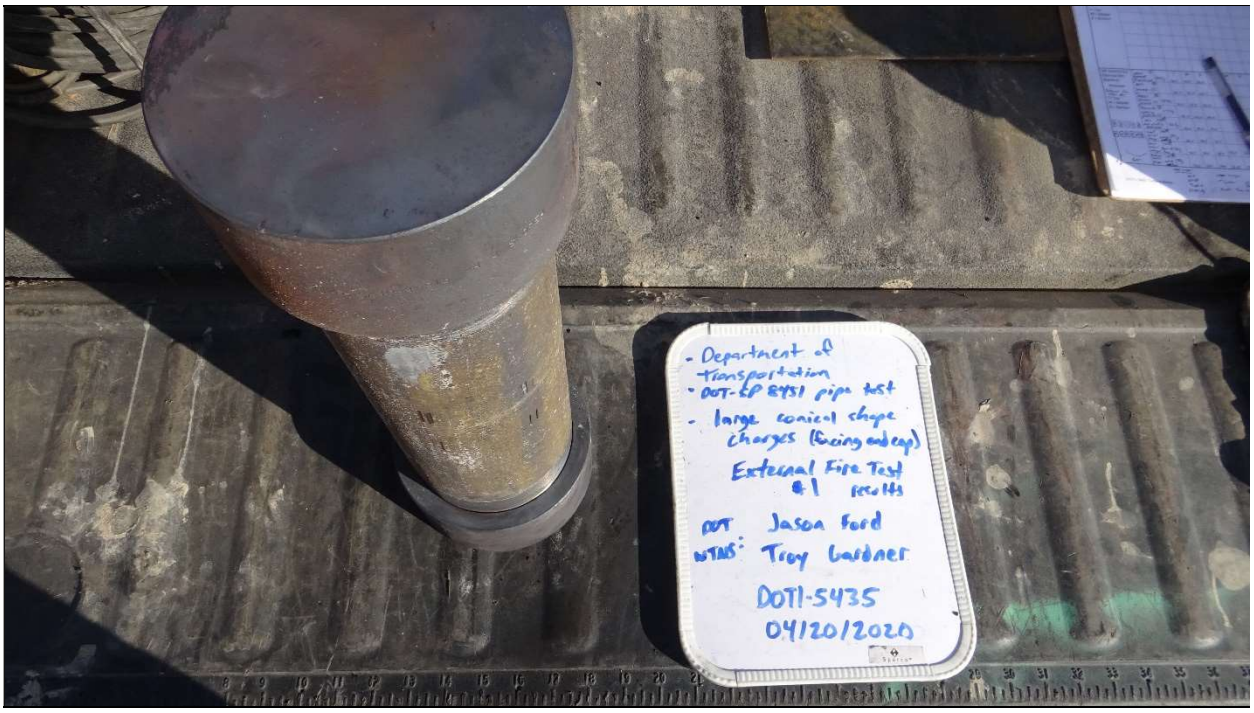


Photo 159: External Fire Test Results (Article in Center) for Sample ID #7C - Conical Shaped Charge, large (stacked face-to-end) without detonator

Photo 160: External Fire Test Results (Article in Center) for Sample ID #7C - Conical Shaped Charge, large (stacked face-to-end) with detonator

Photo 161: External Fire Test Results (Article in Center) for Sample ID #8A - Conical Shaped Charge, small (face-to-face) without detonator

Photo 162: External Fire Test Results (Article in Center) for Sample ID #8A - Conical Shaped Charge, small (face-to-face) with detonator

Photo 163: External Fire Test Results (Article in Center) for Sample ID #8B - Conical Shaped Charge, medium (face-to-face) without detonator

Photo 164: External Fire Test Results (Article in Center) for Sample ID #8B - Conical Shaped Charge, medium (face-to-face) with detonator

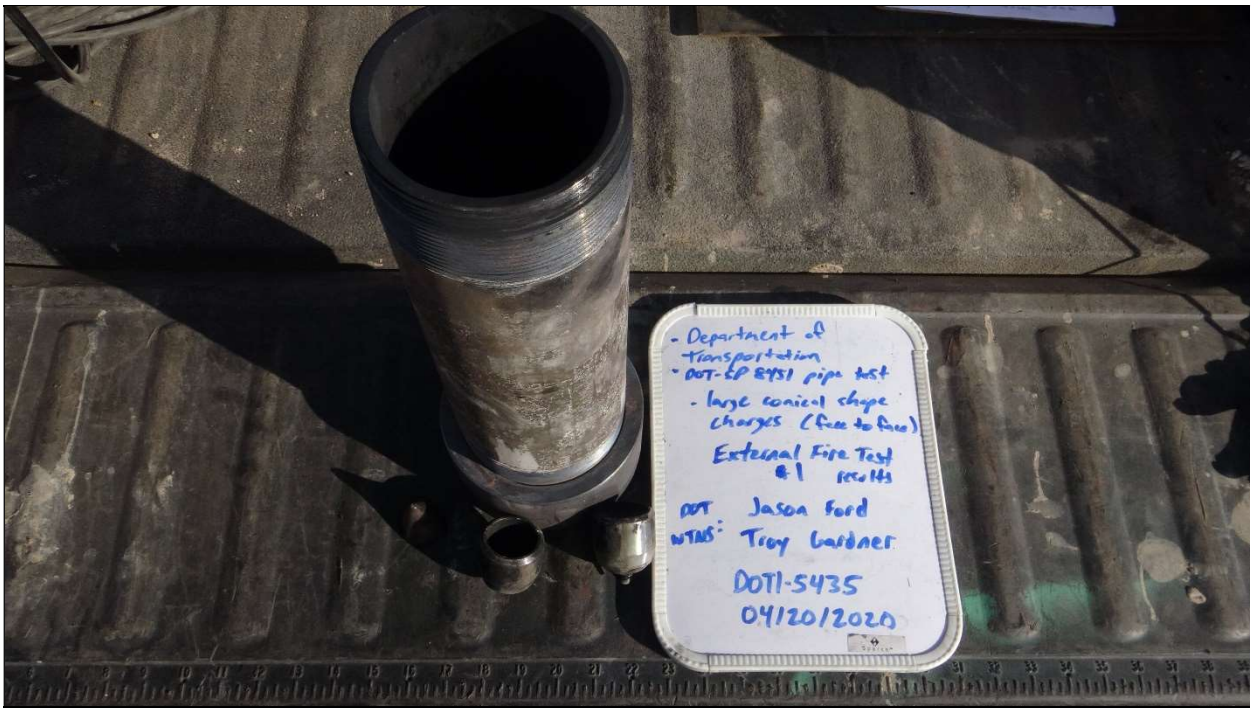


Photo 165: External Fire Test Results (Article in Center) for Sample ID #8C - Conical Shaped Charge, large (face-to-face) without detonator

Photo 166: External Fire Test Results (Article in Center) for Sample ID #8C - Conical Shaped Charge, large (face-to-face) with detonator

Photo 167: External Fire Test Results (Article in Center) for Sample ID #9A - Detonating Cord, small with detonator

Photo 168: External Fire Test Results (Article in Center) for Sample ID #9B - Detonating Cord, medium with detonator

Photo 169: External Fire Test Results (Article in Center) for Sample ID #10A1 - Fragmenting Warhead/Bomblets, thin wall with detonator

Photo 170: External Fire Test Results (Article in Center) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball) with detonator

Photo 171: External Fire Test Results (Article in Center) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball) without detonator

Photo 172: External Fire Test Results (Article in Center) for Sample ID #10B - Fragmenting Warhead/Bomblets, medium wall with detonator and hardened ball

Photo 173: External Fire Test Results (Article in Center) for Sample ID #10C - Fragmenting Warhead/Bomblets, thick wall with detonator and hardened ball

Photo 174: External Fire Test Results (Article in Center) for Sample ID's #11B1 & #11B2 - Cannon with Armor Piercing Projectile, medium diameter

Photo 175: External Fire Test Results (Article in Center) for Sample ID #12B - Ammunition Cartridge, medium diameter with HEI projectile

Photo 176: External Fire Test Results (Article in Center) for Sample ID #13B1 - High Explosive Projectile, fragmenting, medium

Photo 177: External Fire Test Results (Article in Center) for Sample ID #13B2 - High Explosive Projectile, fragmenting, medium

Photo 178: External Fire Test Results (Article in Center) for Sample ID #13C - High Explosive Projectile, fragmenting, large

Photo 179: External Fire Test Results (Article in Center) for Sample ID #14B - Fuze, medium with detonator

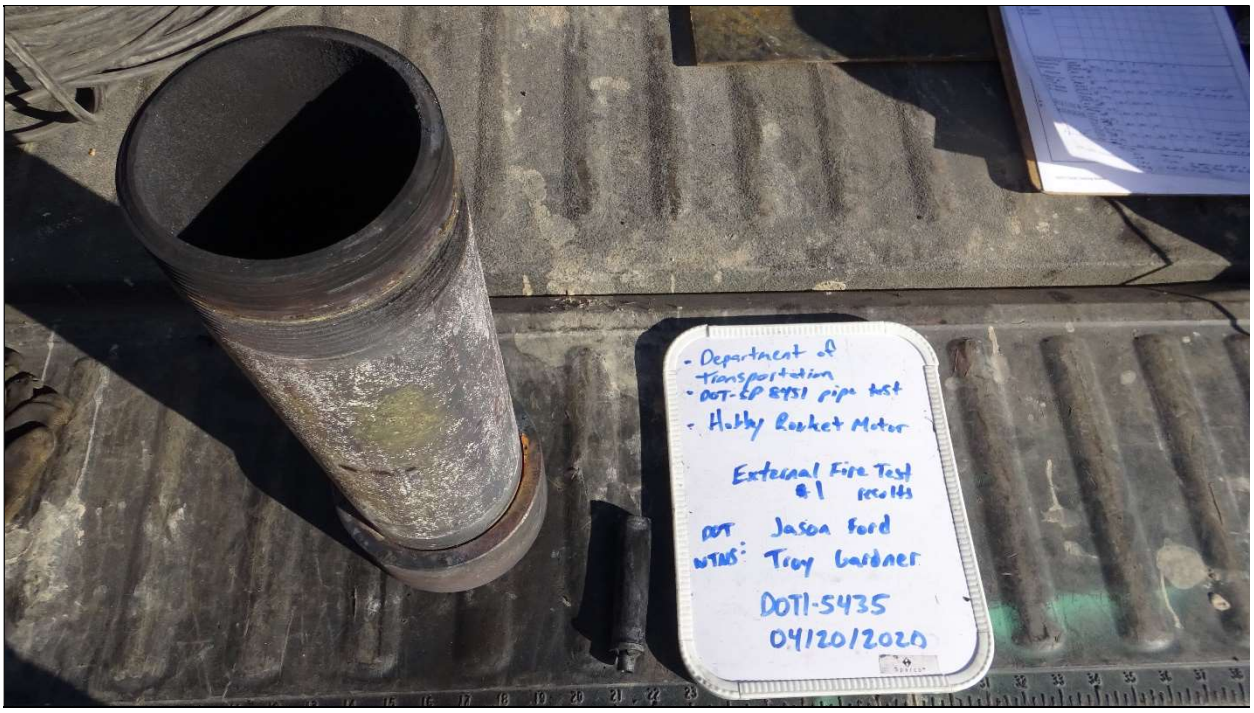


Photo 180: External Fire Test Results (Article in Center) for Sample ID #15C - Rocket Motor, large

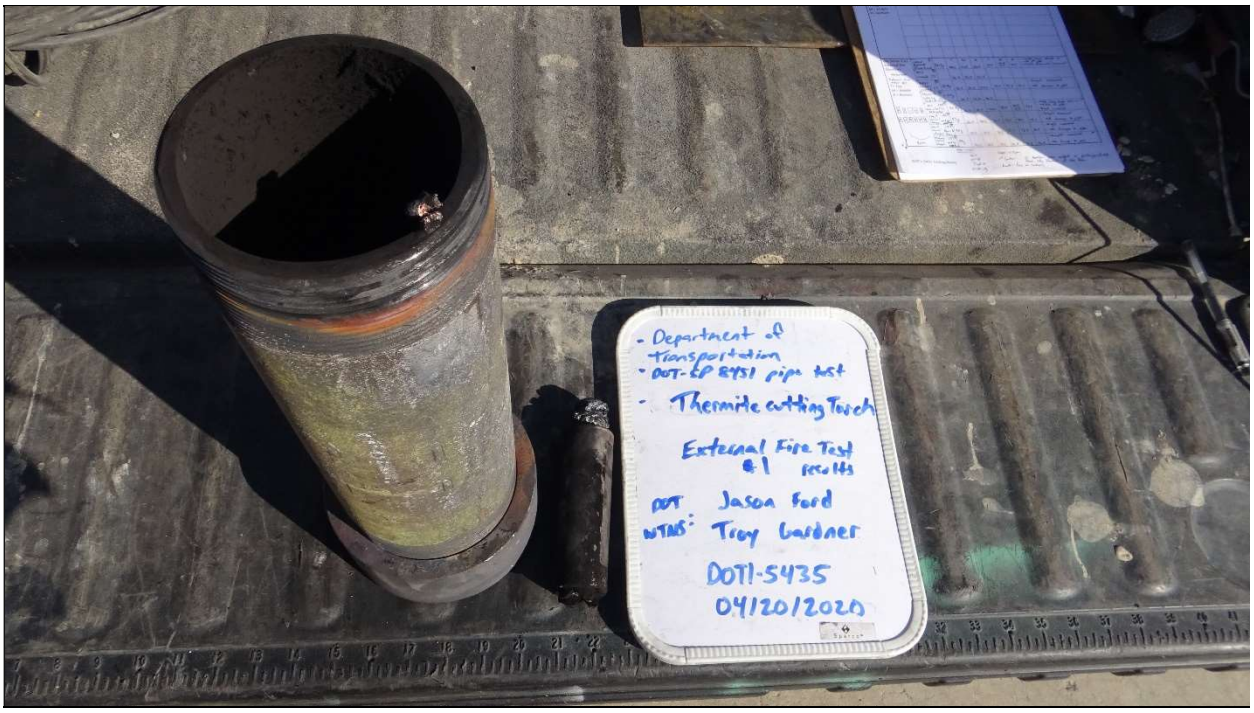


Photo 181: External Fire Test Results (Article in Center) for Sample ID #16C - Thermite Cutting Torch, large

Photo 182: External Fire Test Results (Article in Center) for Sample ID #17A - Conical Shaped Charge, small (interconnected & facing sideways) with detonator

Photo 183: External Fire Test Results (Article in Center) for Sample ID #17B - Conical Shaped Charge, medium (interconnected & facing sideways) with detonator

Photo 184: External Fire Test Results (Article in Center) for Sample ID #17C - Conical Shaped Charge, large (facing sideways) with detonator

6.2.4 *Test Results - Articles Contacting Sidewall of Containment Pipe*

The test results for each substance contacting the sidewall of the DOT-SP 8451, 4-inch diameter containment pipe in a bonfire are summarized in the following table.

Table 22: External Fire Test Results (Articles Contacting Sidewall)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	2B	27	36.4	**36.6**	36.4	w/ detonator: Slight bulge near center of wall
2	4C2	37.5	**36.8**	36.4	36.4	w/ detonator: Pipe blown out of pan (approximately 50 feet); end cap blown out of pan (approximately 70 feet); small hole in end cap (1 x 1 cm)
3	5A	25.0	**37.4**	36.4	36.4	w/o detonator: Bulge near and at top threads; pipe perforation slit open (5 x 1 cm)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
4	6C	50.0	**37.5**	36.5	36.4	w/ detonator: End cap blown off; threads bulged outward; no perforation in pipe nipple
5	7C	25.0	37.0	**42.7**	36.5	w/ detonator: Large bulge at center of pipe; perforation at largest portion of bulge (1 x 3 cm slit)
6	10A2	45.8	36.4	**44.0**	36.4	w/ detonator: Large hole in center of pipe (4.5 x 6 cm) and large bulge in center of pipe; no visible damage to end caps
7	13C	48.0 (+ 20)	36.4	**39.8**	36.4	w/ detonator & booster: Large bulge at center of pipe; perforation at largest portion of bulge (3-cm long slit); no visible damage to end caps
8	17B	33.0	**39.0**	36.4	36.4	w/ detonator: Three large holes in sidewall of pipe (~1.7-cm diameter each) and large bulge in pipe opposite holes; no visible damage to end caps

The test results are shown in the following photos.

Photo 185: External Fire Test Results (Article Contacting Sidewall) for Sample ID #2B - Booster (metal cased), medium with detonator

Photo 186: External Fire Test Results (Article Contacting Sidewall) for ID #4C2 - Grenade, fragmenting (pre-formed), large with detonator

Photo 187: External Fire Test Results (Article Contacting Sidewall) for Sample ID #5A - Linear Shaped Charge, small without detonator

Photo 188: External Fire Test Results (Article Contacting Sidewall) for Sample ID #6C - Linear Shaped Charge, large (face-to-face) with detonator

Photo 189: External Fire Test Results (Article Contacting Sidewall) for Sample ID #7C - Conical Shaped Charge, large (single) with detonator

Photo 190: External Fire Test Results (Article Contacting Sidewall) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball) with detonator

Photo 191: External Fire Test Results (Article Contacting Sidewall) for ID #13C - High Explosive Projectile, fragmenting, large with detonator

Photo 192: External Fire Test Results (Article Contacting Sidewall) for Sample ID #17B - Conical Shaped Charge, medium (interconnected & facing sideways) with detonator

6.2.5 *Test Results - Articles in Containment Pipe with Perlite Blast Mitigation*

The test results for each substance centered in the DOT-SP 8451, 4-inch diameter containment pipe filled with perlite in a bonfire are summarized in the following table.

Table 23: External Fire Test Results (Perlite Blast Mitigation)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	6C	50.0	36.4	**37.0**	36.4	w/ detonator: No damage to end caps, no visible bulge in center however measured slight bulge in center of pipe
2	7C	25.0	36.4	**39.0**	36.4	w/ detonator: Slightly visible bulge in center diameter; 0.5-cm hole in end cap
3	8C	50.0	39.0	**41.0**	36.4	w/ detonator: Large bulge in center of pipe nipple; small hole in end cap
4	10A2	45.8	36.4	**See Results**	36.4	w/ detonator: Very large hole in sidewall (damaged almost entire circumference of pipe); no damage to end caps
5	17B	33.0	36.4	36.4	36.4	w/ detonator: No visible damage to pipe or end caps

The test results are shown in the following photos.

Photo 193: External Fire Test Results (Perlite Blast Mitigation) for Sample ID #6C - Linear Shaped Charge, large (face-to-face) with detonator

Photo 194: External Fire Test Results (Perlite Blast Mitigation) for Sample ID #7C - Conical Shaped Charge, large (single) with detonator

Photo 195: External Fire Test Results (Perlite Blast Mitigation) for Sample ID #8C - Conical Shaped Charge, large (face-to-face) with detonator

Photo 196: External Fire Test Results (Perlite Blast Mitigation) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball) with detonator

Photo 197: External Fire Test Results (Perlite Blast Mitigation) for Sample ID #17B - Conical Shaped Charge, medium (interconnected & facing sideways) with detonator

6.2.6 *Test Results - Articles in Containment Pipe with Metal-Sleeve Blast Mitigation*

The test results for each substance centered in the DOT-SP 8451, 4-inch diameter containment pipe lined with a metal-sleeve in a bonfire are summarized in the following table.

Table 24: External Fire Test Results (Metal-Sleeve Blast Mitigation)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	6C	50.0	36.4	**38.6**	36.4	w/ detonator: Large bulge in center of pipe nipple with hairline fracture; no visible damage to end caps
2	7C	25.0	36.4	36.4	36.4	w/ detonator: End cap blown off; five threads were stripped; no perforation in pipe nipple
3	8C	50.0	**39.0**	36.4	36.4	w/ detonator: Large bulge at top of pipe nipple with hairline fracture; no visible damage to end caps
4	10A2	45.8	36.4	36.4	36.4	w/ detonator: No visible damage to pipe or end caps

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
5	17B	33.0	36.4	36.4	36.4	w/ detonator: Small hole on side of end cap (~1.5 cm); no damage to end caps

The test results are shown in the following photos.

Photo 198: External Fire Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #6C - Linear Shaped Charge, large (face-to-face) with detonator

Photo 199: External Fire Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #7C - Conical Shaped Charge, large (single) with detonator

Photo 200: External Fire Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #8C - Conical Shaped Charge, large (face-to-face) with detonator

Photo 201: External Fire Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball) with detonator

Photo 202: External Fire Test Results (Metal-Sleeve Blast Mitigation) for Sample ID #17B - Conical Shaped Charge, medium (interconnected & facing sideways) with detonator

6.2.7 *Test Results - Articles in Containment Pipe with Rubber-Sleeve Blast Mitigation*

The test results for each substance centered in the DOT-SP 8451, 4-inch diameter containment pipe lined with a rubber-sleeve in a bonfire are summarized in the following table.

Table 25: External Fire Test Results (Rubber-Sleeve Blast Mitigation)

Item	Sample ID	Mass (g)	Top (cm)	Middle (cm)	Bottom (cm)	Results
1	6C	50.0	36.4	36.4	36.4	w/ detonator: No visible damage to pipe or end caps
2	7C	25.0	36.4	36.6	**36.7**	w/ detonator: Small bulge at bottom and center of pipe; no visible damage to end caps
3	8C	50.0	**See Results**	36.4	36.4	w/ detonator: Tear in sidewall of pipe (12 x 9 cm); end cap blown off pipe
4	10A2	45.8	36.4	36.4	36.4	w/ detonator: No visible damage to pipe or end caps
5	17B	33.0	36.4	**38.7**	36.4	w/ detonator: Two holes in sidewall of pipe (~1.5-cm diameter each) and large bulge in center of pipe; no visible damage to end caps

The test results are shown in the following photos.

Photo 203: External Fire Test Results (Rubber-Sleeve Blast Mitigation) for Sample ID #6C - Linear Shaped Charge, large (face-to-face) with detonator

Photo 204: External Fire Test Results (Rubber-Sleeve Blast Mitigation) for Sample ID #7C - Conical Shaped Charge, large (single) with detonator

Photo 205: External Fire Test Results (Rubber-Sleeve Blast Mitigation) for Sample ID #8C - Conical Shaped Charge, large (face-to-face) with detonator

Photo 206: External Fire Test Results (Rubber-Sleeve Blast Mitigation) for Sample ID #10A2 - Fragmenting Warhead/Bomblets, thin wall (without hardened ball) with detonator

Photo 207: Unconfined Package Test Results (Rubber-Sleeve Blast Mitigation) for Sample ID #17B - Conical Shaped Charge, medium (interconnected & facing sideways) with detonator

6.3 Examination of Test Results

6.3.1 *Worst-case Effects for Articles Centered in the Pipe and in Contact with Sidewall*

The test results are summarized in the following table for the explosive articles centered within the pipe (all articles) and in contact with the sidewall (eight articles) in the UN Series 6 (d) Unconfined package and 6 (c) External fire tests. Results are denoted by:

- **X** for no measurable damage,
- **Maximum circumference in centimeters** (starting with a baseline value of **36.4** cm), or
- **P** for perforation of the shipping pipe.

Table 26: Summary of UN Series 6 Test Results for Explosive Articles in the DOT-8451 Shipping Pipe - Maximum Circumference of Pipe

Sample ID	N.E.W.		Centered		Sidewall	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)
1B	10	30	37.3	X		
1C	20 + 10	30	36.8	X		
2B	9	27	P	37.8	P	36.6
3A	1.3	29.9	36.7	37.2		

Sample ID	N.E.W.		Centered		Sidewall	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)
4C1	30.5	30.5	P	X		
4C2	37.5	37.5	38.8	X*	P	P
				P		
5A	25.0	25.0	36.7	P*	P	P
				P		
5B	12.5	37.5	P	P	P	
5C	25.0	25.0	P	36.5*		
				P		
5D	25.0	25.0	37.5	X*		
				P		
6A	25.0	50.0	P	X*		
				38.0		
6C	25.0	50.0	P	X*	P	P
				X		
6D	25.0	50.0	38.0	X*		
				X		
7A	3.2	28.8	P	X*		
				38.0		
7B	11.0	33.0	P	X*		
				P		
7C	25.0	25.0	P	X*	P	P
				42.7		
8A	3.2	32.0	36.7	X*		
				37.0		
8B	11.0	44.0	P	X*		
				38.5		
8C	25.0	50.0	P	X*		
				37.0		
9A	25.0	25.0	36.5	36.5		
9B	25.0	25.0	36.6	36.8		
10A1	45.8	45.8	P	P		
10A2	45.8	45.8	P	P	P	P
				X*		
10B	45.8	45.8	P	P		
10C	45.8	45.8	40.5	P		
11B1	25	25	X	X		
11B2	25	25	X	X		
12B	^	^	36.6	X		

Sample ID	N.E.W.		Centered		Sidewall	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)
13B1	4.6	32.2 (+ 20)	X	36.7		
13B2	4.6	23.0 (+ 20)	36.8	37.2		
13C	48.0	48.0 (+ 20)	39.5	37.0	P	P
14B	9.3	27.9 (+ 20)	X	X* 39.0		
15C	25.8	25.8	X	X		
16C	50	50	X	X		
17A	3.2	25.6	P	P		
17B	11.0	33.0	P	P	P	P
17C	25.0	25.0	P	P		
* Without detonator ^ Refer to military specifications.						

The following table is the same as the preceding one except with the maximum circumference in centimeters divided by the baseline value of 36.4 cm and reduced by 100% to show the percent increase from baseline pipe circumference.

Table 27: Summary of UN Series 6 Test Results for Explosive Articles in the DOT-8451 Shipping Pipe - Percent Increase in Pipe Circumference

Sample ID	N.E.W.		Centered		Sidewall	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)
1B	10	30	2.5%	X		
1C	20 + 10	30	1.1%	X		
2B	9	27	P	3.8%	P	0.5%
3A	1.3	29.9	0.8%	2.2%		
4C1	30.5	30.5	P	X		
4C2	37.5	37.5	6.6%	X* P	P	P
5A	25.0	25.0	0.8%	P* P	P	P
5B	12.5	37.5	P	P	P	
5C	25.0	25.0	P	0.3% P		
5D	25.0	25.0	3.0%	X*		

Sample ID	N.E.W.		Centered		Sidewall	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)
				P		
6A	25.0	50.0	P	X*		
				4.4%		
6C	25.0	50.0	P	X*	P	P
				X		
6D	25.0	50.0	4.4%	X*		
				X		
7A	3.2	28.8	P	X*		
				4.4%		
7B	11.0	33.0	P	X*		
				P		
7C	25.0	25.0	P	X*	P	P
				17.3%		
8A	3.2	32.0	0.8%	X*		
				1.6%		
8B	11.0	44.0	P	X*		
				5.8%		
8C	25.0	50.0	P	X*		
				1.6%		
9A	25.0	25.0	0.3%	0.3%		
9B	25.0	25.0	0.5%	1.1%		
10A1	45.8	45.8	P	P		
10A2	45.8	45.8	P	P	P	P
				X*		
10B	45.8	45.8	P	P		
10C	45.8	45.8	11.3%	P		
11B1	25	25	X	X		
11B2	25	25	X	X		
12B	^	^	0.5%	X		
13B1	4.6	32.2 (+ 20)	X	0.8%		
13B2	4.6	23.0 (+ 20)	1.1%	2.2%		
13C	48.0	48.0 (+ 20)	8.5%	1.6%	P	P
14B	9.3	27.9 (+ 20)	X	X*		
				7.1%		
15C	25.8	25.8	X	X		
16C	50	50	X	X		

Sample ID	N.E.W.		Centered		Sidewall	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)
17A	3.2	25.6	P	P		
17B	11.0	33.0	P	P	P	P
17C	25.0	25.0	P	P		
* Without detonator ^ Refer to military specifications.						

Here is the table rearranged in groups of small, medium, and large to determine assess whether there is a clear pattern based on the net explosive weight per unit.

Table 28: Summary of UN Series 6 Test Results for Explosive Articles in the DOT-8451 Shipping Pipe - Data Grouped by Unit Size

Sample ID	N.E.W.		Centered		Sidewall	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)
Small (A)						
3A	1.3	29.9	0.8%	2.2%		
5A	25.0	25.0	0.8%	P*	P	P
				P		
6A	25.0	50.0	P	X*		
				4.4%		
7A	3.2	28.8	P	X*		
				4.4%		
8A	3.2	32.0	0.8%	X*		
				1.6%		
9A	25.0	25.0	0.3%	0.3%		
10A1	45.8	45.8	P	P		
10A2	45.8	45.8	P	P	P	P
				X*		
17A	3.2	25.6	P	P		
Medium (B)						
1B	10	30	2.5%	X		
2B	9	27	P	3.8%	P	0.5%
5B	12.5	37.5	P	P	P	
7B	11.0	33.0	P	X*		
				P		
8B	11.0	44.0	P	X*		
				5.8%		
9B	25.0	25.0	0.5%	1.1%		
10B	45.8	45.8	P	P		

Sample ID	N.E.W.		Centered		Sidewall	
	Unit (g)	Sum (g)	6 (d)	6 (c)	6 (d)	6 (c)
11B1	25	25	X	X		
11B2	25	25	X	X		
12B	^	^	0.5%	X		
13B1	4.6	32.2 (+ 20)	X	0.8%		
13B2	4.6	23.0 (+ 20)	1.1%	2.2%		
14B	9.3	27.9 (+ 20)	X	X* 7.1%		
17B	11.0	33.0	P	P	P	P
Large (C)						
1C	20 + 10	30	1.1%	X		
4C1	30.5	30.5	P	X		
4C2	37.5	37.5	6.6%	X* P	P	P
5C	25.0	25.0	P	0.3% P		
6C	25.0	50.0	P	X* X	P	P
7C	25.0	25.0	P	X* 17.3%	P	P
8C	25.0	50.0	P	X* 1.6%		
10C	45.8	45.8	11.3%	P		
13C	48.0	48.0 (+ 20)	8.5%	1.6%	P	P
15C	25.8	25.8	X	X		
16C	50	50	X	X		
17C	25.0	25.0	P	P		
5D	25.0	25.0	3.0%	X*		
6D	25.0	50.0	4.4%	X* X		

* Without detonator
^ Refer to military specifications.

Based on this data grouping, there does not appear to be a clear relationship between the ability to perforate/breach the DOT-SP 8451 shipping pipe and a unit's individual net explosive weight when packed in bulk.

For the sidewall study, each article that was placed in contact with the sidewall produced more damage to the shipping pipe than that of the same article positioned in the center of the pipe. For example, the UN Series 6 test results for Sample ID #13C were fully contained when the article was in the center; placing the article in contact with the sidewall resulted in perforation/breaching of the shipping pipe. Test results for the articles in contact with the sidewall were consistently more severe than that of test results for articles in the center.

Based on the test results, the explosive articles in the following table resulted in no external damage to the DOT-SP 8451 shipping pipe in the UN Series 6 tests.

Table 29: Test Samples with No External Damage to the DOT-SP 8451 Shipping Pipe

Sample ID	Article Type
11B1	Cannon with armor piercing projectile, medium diameter
11B2	Cannon with armor piercing projectile, medium diameter
15C	Rocket motor, large
16C	Thermite cutting torch, large

Explosive articles that were unable to perforate/breach the DOT-SP 8451 shipping pipe in the UN Series 6 tests are listed in the following table.

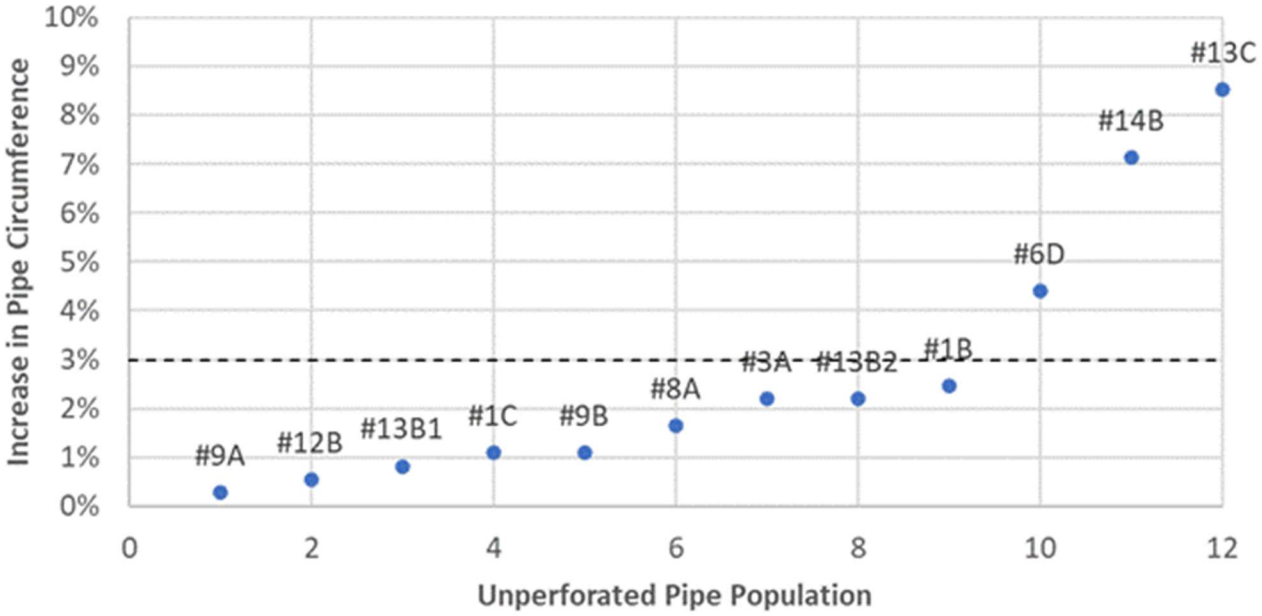
Table 30: Test Samples that did NOT Perforate/Breach the DOT-SP 8451 Shipping Pipe

Sample ID	Article Type
1B	Booster (non-cased), medium
1C	Booster (non-cased), large
3A	Detonator, small
6D	Linear shaped charge, X-large (face-to-face)
8A	Conical shaped charge, small (face-to-face)
9A	Detonating cord, small
9B	Detonating cord, medium
12B	Ammunition cartridge, medium with HEI projectile
13B1	High explosive projectile, fragmenting, medium
13B2	High explosive projectile, fragmenting, medium
13C*	High explosive projectile, fragmenting, large
14B	Fuze, medium
*Perforated the shipping pipe when in contact with the pipe's sidewall	

The following figure shows the percent increase from baseline pipe circumference for each of the articles that did not perforate/breach the DOT-SP 8451 shipping pipe. Over eighty percent of the articles produced less than a three percent increase in the baseline pipe circumference.

Articles that produced a greater than three percent increase in pipe circumference include Sample ID's #6D (50 grams N.E.W), #14B (47.9 grams N.E.W.), and #13C (68.0 N.E.W.).

Figure 24: Percent Increase from Baseline Pipe Circumference that did not Perforate/Breach the DOT-SP 8451 Shipping Pipe



Conversely, the explosive articles in the following table were able to perforate/breach the shipping pipe in the UN Series 6 tests.

Table 31: Test Samples that Perforated/Breached the DOT-SP 8451 Shipping Pipe

Sample ID	Article Type
2B	Booster (metal cased), medium
4C1	Grenade, fragmenting (pre-formed), large
4C2	Grenade, fragmenting (pre-formed), large
5A	Linear shaped charge, small
5B	Linear shaped charge, medium
5C	Linear shaped charge, large
5D	Linear shaped charge, X-large
6A	Linear shaped charge, small (face-to-face)
6C	Linear shaped charge, large (face-to-face)
7A	Conical shaped charge, small (stacked face-to-end)
7B	Conical shaped charge, medium (stacked face-to-end)
7C	Conical shaped charge, large (single)
8B	Conical shaped charge, medium (face-to-face)

Sample ID	Article Type
8C	Conical shaped charge, large (face-to-face)
10A1	Fragmenting warhead/bomblets, thin wall
10A2	Fragmenting warhead/bomblets, thin wall (without hardened ball)
10B	Fragmenting warhead/bomblets, medium wall
10C	Fragmenting warhead/bomblets, thick wall
13C*	High explosive projectile, fragmenting, large
17A	Conical shaped charge, small (interconnected & facing sideways)
17B	Conical shaped charge, medium (interconnected & facing sideways)
17C	Conical shaped charge, large (facing sideways)
*Perforated the shipping pipe when in contact with the pipe's sidewall	

Sample ID's #13B1 and #13B2 were unable to increase the circumference of the pipe greater than 3%; Sample ID #13C was able to increase the circumference of the pipe 8.5% but contained a net explosive weight of 68.0 grams (much greater than DOT-SP 8451's 25-gram capacity). Based on these test results, articles producing a shaped-charge jet effect or penetrating fragments, excluding those produced by projectiles containing high explosives and/or incendiaries, may perforate or breach the DOT-SP 8451 shipping pipe.

6.3.2 *Blast Attenuation/Mitigation*

Blast attenuation/mitigation strategies were pursued to determine whether the hazardous effects could be suppressed and contained within the shipping pipe. The test results are summarized in the following table for the explosive articles with blast attenuation/mitigation employed (five articles each for perlite fill, 0.22-inch thick steel lining, and 0.50-inch thick rubber lining) in the UN Series 6 (d) Unconfined package and 6 (c) External fire tests.

Table 32: Summary of UN Series 6 Test Results for Blast-Mitigated Explosive Articles in the DOT-8451 Shipping Pipe - Maximum Circumference of Pipe

Sample ID	N.E.W.		Centered		Blast Attenuation/Mitigation Strategy					
	Unit (g)	Sum (g)			Perlite Fill		Steel		Rubber	
			6 (d)	6 (c)	6 (d)	6 (c)	6 (d)	6 (c)	6 (d)	6 (c)
6C	25.0	50.0	P	X	P	37.0	37.1	P	41.1	X
7C	25.0	25.0	P	42.7	P	39.0	P	P	P	36.7
8C	25.0	50.0	P	37.0	39.4	P	38.0	P	40.0	P
10A2	45.8	45.8	P	P	P	P	P	X	P	X
17B	11.0	33.0	P	P	P	X	P	P	P	P

The following table is the same as the preceding one except with the maximum circumference in centimeters divided by the baseline value of 36.4 cm and reduced by 100% to show the percent increase from baseline pipe circumference.

Table 33: Summary of UN Series 6 Test Results for Blast-Mitigated Explosive Articles in the DOT-8451 Shipping Pipe - Percent Increase in Pipe Circumference

Sample ID	N.E.W.		Centered		Blast Attenuation/Mitigation Strategy					
	Unit (g)	Sum (g)			Perlite		Steel		Rubber	
			6 (d)	6 (c)	6 (d)	6 (c)	6 (d)	6 (c)	6 (d)	6 (c)
6C	25.0	50.0	P	X	P	1.6%	1.9%	P	12.9%	X
7C	25.0	25.0	P	17.3%	P	7.1%	P	P	P	0.8%
8C	25.0	50.0	P	1.6%	8.2%	P	4.4%	P	9.9%	P
10A2	45.8	45.8	P	P	P	P	P	X	P	X
17B	11.0	33.0	P	P	P	X	P	P	P	P

Based on the test results, the tested coarse perlite fill, 0.22-inch thick steel lining, and 0.50-inch thick rubber lining generally reduced the damage to the DOT-SP 8451 shipping pipe from the shaped-charge jets of Sample ID's #6C, #7C, #8C, and #17B and the steel fragments of Sample ID #10A2, but failed to consistently prevent perforation of the shipping pipe. Therefore, the tested blast attenuation/mitigation strategies are not recommended for adoption/inclusion in the DOT-SP 8451 special permit.

7.0 FURTHER RESEARCH

1. The three tested blast mitigation strategies were unable to consistently prevent perforation of the shipping pipe by articles producing a shaped-charge jet effect or penetrating fragments; additional blast mitigation strategies could be investigated to prevent perforation of the shipping pipe.

2. Additional testing could be performed for fragmenting articles in DOT-SP 8451 6-inch shipping pipes to determine whether the larger containers can consistently prevent perforation through larger containment volumes and thicker blast mitigation; the blast mitigation thickness is more limited in a 4-inch shipping pipe.

8.0 REFERENCES

1. U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) Special Permit (SP) DOT-SP 8451, Forty-first revision, June 27, 2019.

9.0 PRODUCT DATA SHEETS

9.1 Rubber Lining (0.50-inch thick)

EPDM - Commercial Grade - 60A

Specifications
March 2014

Description:	Ethylene Propylene Diene Monomer (EPDM) and SBR blended sheet is a black colored sheet rubber which provides very good resistance to weathering, ozone and UV exposure.
Compound:	10% Ethylene Propylene Diene Monomer (EPDM) Base, SBR
Color:	Black
Weight:	Approximate weight per square foot: 1/8" weighs 1-1/4 lbs.
Durometer:	60 Shore A, +/- 5
Temperature Range:	-40 F to 212 F
Minimum Tensile:	725 PSI or 5 MPA
Finish:	Smooth
Minimum Elongation:	300%
Gauges:	1/16", 3/32", 1/8", 3/16", 1/4", 3/8", 1/2" (custom gauges up to 2" thick are available upon request)
Widths:	36" (custom widths up to 78" are available upon request)
Roll Length:	25' or 50' depending on thickness.
PSA:	Pressure sensitive adhesive can be applied to this product upon request.
Chemical Resistance:	Good resistance to UV rays and ozone. Good resistance to Anti-freeze, Synthetic Detergents, Acetone, Boric acid, Ethanol, Formaldehyde, Mercury, Potassium Sulfate, Silver Nitrate, Steam (up to 212 Fahrenheit), Saccharin. For EPDM Blend's compatibility with your specific medium please consult a Rubber-Cal representative.
Applications:	Provides outstanding resistance to weathering, ozone and UV exposure. Gasket, bumper and general exterior applications.
Flexibility:	This medium durometer (55-65) sheet rubber offers good pliability and elasticity.
Custom Cuts:	In addition to hand fabrication, this product can be fabricated using laser, die, and water-jet cut. Please submit your drawings for a price quote.
Availability:	Popular gauges are generally in stock.

Rubber Cal

Rubber-Cal, Inc.
620 West Warner Ave
Santa Ana, CA 92707
800-370-9152
www.rubbercal.com

9.2 Sample ID #1B & #1C - Booster (non-cased)

TROJAN® STINGER®

Technical Information

BOOSTERS • CORDS

Superprime® Cast Booster

Product Description
TROJAN STINGER Superprime cast boosters are detonator sensitive, high density, high energy molecular explosives specially designed for use in small diameter boreholes. They are particularly suited for use in underground blasting operations. Most commercially available electric and nonelectric detonators will fit into the molded plastic capwell. TROJAN STINGER cast boosters are manufactured using a homogeneous mixture of pure pentolite for superior performance, reliability, consistency and durability.

Application Recommendations
- ALWAYS insert the detonator fully into the detonator-well so that the base of the detonator is against the bottom of the detonator-well.
- ALWAYS confirm that the TROJAN STINGER charge weight exceeds the initiation sensitivity requirement for the main explosive charge. Consult the explosives product literature or the manufacturer if you have any questions.
- NEVER force the detonator into the detonator-well or otherwise attempt to clear this area if obstructed. If the detonator-well does not accommodate the detonator, do not use the booster. Notify your Dyno Nobel representative.
- NEVER use the TROJAN STINGER if the detonator fits loosely or cannot be inserted fully into the detonator-well. The TROJAN STINGER is designed to be used with Dyno Nobel detonators. Detonators made by other manufacturers may not fit into the detonator-well.

Properties

SDS #1108

Density	(g/cc) Avg	1.60
Velocity	(m/sec)	7,800
	(ft/s)	25,600
Detonation Pressure (Kbars)		245
Water Resistance		6 months with no loss of sensitivity
Shelf Life Maximum		5 years (from date of production)
Maximum Usage Temperature		66°C (150°F)

All Dyno Nobel Inc. energy and gas volume values are calculated using PRODET™ the computer code developed by Dyno Nobel Inc. for its exclusive use. Other computer codes may give different values.

Hazardous Shipping Description
Boosters, 1.1D, UN 0042 PG II EX 2011010500

1.1D
1

C-09-10-04-11

See Product Disclaimer on page 2

DYNO Dyno Nobel
Groundbreaking Performance

TROJAN® STINGER®

Technical Information

Application Recommendations (continued)

- Minimum detonator is No. 8 strength for temperatures above -40° C (-40° F). A high strength detonator is recommended for temperatures below -40° C (-40° F).
- Extremely low temperatures do not affect the performance of cast boosters with commercial detonators. Low temperatures do affect detonators and detonating cord. Be certain your initiation system is suitable for your application in extremely low temperatures. Cast boosters are more susceptible to breakage during handling in extremely cold temperatures.

Transportation, Storage and Handling

- TROJAN cast boosters must be transported, stored, handled and used in conformity with all federal, state, provincial and local laws and regulations.
- For maximum shelf life (5 years), TROJAN cast boosters must be stored in a cool, dry, well ventilated magazine. Explosive inventory should be rotated. Avoid using new materials before the old.

Packaging

Unit Weight		Unit Dimensions				Case Quantity	Gross Weight/ Case	
		Length		Diameter				
g	oz	cm	in	cm	in		kg	lbs
10	0.353	7.6	3.0	1.5	0.6	500	7.8	17.1
20	0.705	8.9	3.5	1.7	0.7	576	13.5	29.7

Note: All weights and dimensions are approximate.

Case Dimensions

10 gram	24 x 24 x 41 cm	9½ x 9½ x 16 in
20 gram	46 x 24 x 27 cm	18¼ x 9½ x 10½ in

Dyno Nobel Inc.
2795 East Cottonwood Parkway, Suite 500, Salt Lake City, Utah 84121 USA
Phone 800-732-7534 Fax 801-328-6452 Web www.dynonobel.com

DYNO Dyno Nobel
Groundbreaking Performance

9.3 Sample ID #5A – #6D - Linear Shaped Charges

DESCRIPTION

AES Linear Shaped Charge (LSC) is an explosive enclosed in a seamless metal sheath and fabricated in continuous lengths shaped in the form of an inverted "V". When detonated, the V-shaped metal liner with explosive core produces a uniform linear cutting action. This cutting action, known as the "Monroe effect", can be accentuated by controlling the LSC dimensions and configuration, explosive type and load, liner thickness and continuity. At detonation, the focusing of the explosive high pressure wave as it becomes incident to the side wall causes the metal liner of the LSC to collapse–creating the cutting force. If the standoff distance is optimum, collapse of the liner will be complete before it reaches the target as a plasma jet. This high velocity jet impacts the target with pressures exceeding the target's yield strength and literally pushes the target material to either side of the path of the jet.

PERFORMANCE

The cutting ability of LSC is affected by a number of variables, including the detonation rate of the explosive core load, the characteristics of the metal liners and the density of the material being cut. There is, however, a general scaling guide which may be used to determine the penetration as related to core load, in that penetration of a given material is essentially proportional to the square root of the core load. The liner may be formed using any malleable metal, but is typically copper, aluminum, lead or silver. Copper is generally used with most large core loads, but for some applications, Aluminum is recommended to provide structural integrity. For small core loads where flexibility is required, Lead is preferred, while Silver is reserved primarily for use with thermally-resistant explosive core loads. The explosive core loads commonly used in AES LSC are RDX, HMX, PETN and HNS.

COPPER LINEAR SHAPED CHARGE

Core Load Grains/Foot*	Width** (In.)	Height** (In.)	Approx. Gross Weight (Lbs/Ft.)	Approx. Standoff (In.)	Penetration at Optimum Standoff (In.)
125	.37	.27	.14	.20	.20
250	.46	.38	.22	.35	.40
400	.48	.51	.31	.37	.50
600	.68	.61	.51	.60	.70
900	.72	.69	.70	.66	.85
1,200	.92	.90	.96	.70	1.00
2,000	1.15	1.07	1.31	.75	1.50
3,200	1.43	1.23	1.66	1.00	1.70
4,000	1.55	1.38	2.25	1.15	2.00
10,500	2.23	1.87	4.30	2.50	3.00

ACCURATE ENERGETIC SYSTEMS, LLC
5891 Highway 230 West,
McEwen, Tennessee 37101
Tel: 931-729-4207
Web: www.aesys.biz

9.4 Sample ID #7A-C/#8A-C/#17A-C - Conical Shaped Charges

RAZOR® PERFORATING XDP

Industry-leading shaped charge performance=
Better connection to the reservoir=

BETTER WELL PERFORMANCE

This performance is achieved by combining cutting edge designs, state of the art production processes, and rigorous quality control.

BEST IN CLASS PERFORMANCE

EXTREME DEEP PENETRATING

SYSTEM SIZE	PRODUCT NAME	PART NUMBER	SHOT DENSITY	PHASING	EXPLOSIVE LOAD		CASING SIZE	ENTRANCE HOLE	PENETRATION	
inches			per foot	degrees	grams	explosive	inches	inches	inches	test
1-9/16	1503 RAZOR® XDP	EC1-15A0322	4	0 / 60 / 90	3.2	HMX	2-7/8	0.19	13.09	API RP 43
1-3/4	1705 RAZOR® XDP	EC1-17A0522	4D / 6F	0 / 60 / 90	5.1	HMX	4-1/2	0.26	21.63	API RP 43
2	2007 RAZOR® XDP	EC1-20A0722	6	0 / 60 / 90	6.8	HMX	2-7/8	0.25	22.30	API RP 19B
2-3/8	2311 RAZOR® XDP	EC2-23A1122	6	60	11.0	HMX	3-1/2	0.31	30.11	API RP 43
2-1/2	2511 RAZOR® XDP	EC1-25A1122	6	60	11.5	HMX	3-1/2	0.32	31.10	API RP 19B
2-3/4	2715 RAZOR® XDP	EC2-27A1522	6	60	15.0	HMX	4-1/2	0.39	37.45	API RP 43
2-7/8	2715 RAZOR® XDP	EC2-27A1522	6	60	15.0	HMX	4-1/2	0.34	35.10	API RP 19B
2-7/8	2818 RAZOR® XDP	EC2-28A1822	6	60	18.0	HMX	4-1/2	0.43	40.05	API RP 43
3-1/8	3323 RAZOR® XDP	EC2-33A2322	6	±30 LS / 60 / 180	22.7	HMX	4-1/2	0.42	46.02	API RP 43
3-3/8	3323 RAZOR® XDP	EC2-33A2322	6	±30 LS / 60 / 180	22.7	HMX	4-1/2	0.45	46.32	API RP 43
3-3/8	3325 RAZOR® XDP	EC2-33B2522	6	±30 LS / 60 / 180	25.0	HMX	4-1/2	0.53	47.30	API RP 19B
4	3325 RAZOR® XDP	EC2-33B2522	6	60	25.0	HMX	5-1/2	0.47	46.11	API RP 43
4	4039 RAZOR® XDP	EC2-40A3922	4	60 / 90	39.0	HMX	5-1/2	0.39	53.00	API RP 19B
4-1/2	4039 RAZOR® XDP	EC2-40A3922	5	60	39.0	HMX	7	0.44	62.90	API RP 19B
4-1/2	3323 RAZOR® XDP	EC2-33A2322	12	135-45	22.7	HMX	7	0.38	34.90	API RP 19B
7	4039 RAZOR® XDP	EC2-40A3922	12	135-45	39.0	HMX	9-5/8	0.41	53.60	API RP 43

- Qualified for Shooting in Fluid and Dry

APPLICATIONS

Conventional reservoirs
Unconventional reservoirs
High temperature and high pressure
Plug and perf
Multi-string
Plug and abandonment

EDITION - 01/2017 REV.2

9.5 Sample ID #7A/#8A/#17A - Conical Shaped Charge, small

API FORM 43F

CERTIFICATION DATA SHEET

PERFORATING SYSTEM EVALUATION, RP 43, SECTIONS 1 AND 2

1-9/16" RTG, 4 SPF 0°

EC1-15A0322

Service Company	AVAILABLE TO ALL FROM GEODynamics, INC.	Explosive Weight	3.2 gm, HMX powder, Case Material STEEL
Gun OD & Trade Na	1-9/16" RTG, 4 SPF 0°	Max. Temp, F	400 1 hr ___ 3 hr ___ 24 hr ___ 100 hr ___ hr
Charge Name	1-9/16" GEOcmt XDP	Maximum Pressure Rating	20,000 psi, Carrier Material STEEL
Manufacturer Charge Part No.	EC1-15A0322 Date of Manufacture 7/13/2005	Shot Density	4 shots/ft
Gun Type	SCALLOPED GUN (RETRIEVABLE, EXPENDABLE HOLLOW STEEL CARRIER)	Recommended Minimum ID for Running	1.78 in.
Phasing Tested	0 degrees, Firing Order X Top down, X Bottom up	Available Firing Mode	X Selective, X Simultaneous.
Debris Description	SMALL STEEL PARTICLES MAY EXIT CARRIER	Debris Weight	N/A gm/charge, Debris N/A in.3/charge
Remarks	GUNS MAY BE TUBING OR WIRELINE CONVEYED		

SECTION 1 - CONCRETE TARGET

Casing Data 2-7/8" OD, Weight 6.5 lb/ft, L-80 API Grade, Date of Concrete Test 8/1/2005

Target Data 48 OD, Briquet Compressive Strength 6729 psi, Age of Target 28 days

Shot No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	
Clearence, in.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Casing Hole Diameter, Short Axis, in.	0.19	0.18	0.19	0.19	0.18	0.19	0.19	0.19	0.19	0.19	
Casing Hole Diameter, Long Axis, in.	0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.19	0.19	0.19	
Average Casing Hole Diameter, in.	0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.19	0.19	0.19	
Total Depth, in.	13.50	13.20	12.80	13.80	12.50	13.20	13.40	12.90	13.20	13.10	
Burr Height, in.	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.02	
Shot No.	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18	No. 19	No. 20	Average
Clearence, in.	0.00	0.00									0.00
Casing Hole Diameter, Short Axis, in.	0.19	0.19									0.19
Casing Hole Diameter, Long Axis, in.	0.20	0.19									0.19
Average Casing Hole Diameter, in.	0.20	0.19									0.19
Total Depth, in.	12.50	13.00									13.09
Burr Height, in.	0.04	0.03									0.03

Remarks PENETRATION NORMALIZED TO 5000 PSI CONCRETE WOULD BE 14.22" (5% PER 1,000 PSI)

SECTION 2 - BEREA SANDSTONE CORE TARGET

Berea Bulk Porosity, ______

Date of Berea Test ______

Shot No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	Average
Faceplate Hole Diameter, Short Axis, in.							
Faceplate Hole Diameter, Long Axis, in.							
Average Faceplate Hole Diameter, in.							
Total Depth, in.							

CERTIFICATION

Type of Certification: [X] Self [ ] Third Party

I certify that these tests were made according to the procedures as outlined in API RP 43: Recommended Practices for Evaluation of Well Perforators, Fifth Edition, January 1991. All of the equipment used in these tests, such as the guns, jet charges, detonator cord,etc., was standard with our company for use in the gun being tested, and was not changed in any manner for the test. Furthermore, the equipement was chosen at random from stock and therefore will be substantially the same as the equipement which would be furnished to perforate a well for any operator.

___ CERTIFIED BY
___ RECERTIFIED
X PRELIMINARY

(Company Officer) C.E.O. (Title) 8/1/2005 (Date) GEODynamics, Inc. (Company) 10500 West Interstate 20, Millsap, Texas 76140 (Address)

9.6 Sample ID #7B/#8B/#17B - Conical Shaped Charge, medium

API FORM 43F

CERTIFICATION DATA SHEET
PERFORATING SYSTEM EVALUATION, RP 43, SECTIONS 1 AND 2

2.375-in Expendable Hollow Carrier
EC2-23A1122

Service Company: AVAILABLE FROM GEODynamics, INC.
Gun OD & Trade Na: 2.375-in Expendable Hollow Carrier
Charge Name: 2311 RaZor HMX
Manufacturer Charge Part No.: EC2-23A1122 Date of Manufacture: 6/23/2015
Gun Type: SCALLOPED GUN (RETRIEVABLE, EXPENDABLE HOLLOW STEEL CARRIER)
Phasing Tested: 60 degrees, Firing Order: X Top down, X Bottom up
Debris Description: Small steel chips
Remarks: Maximum gun diameter after shooting in liquid is 2.56 in, Guns may be tubing or wireline conveyed

Explosive Weight: 11 gm, HMX powder, Case Material: STEEL
Max. Temp, F: 400 1 hr ___ 3 hr ___ 24 hr ___ 100 hr ___ hr
Maximum Pressure Rating: 20,000 psi, Carrier Material: STEEL
Shot Density: 6 shots/ft
Recommended Minimum ID for Running: see remarks in.
Available Firing Mode: X Selective, X Simultaneous.
Debris Weight: N/A gm/charge, Debris: N/A in.3/charge

SECTION 1 - CONCRETE TARGET

Casing Data: 3-1/2" OD, Weight: 9.2 lb/ft, L-80 API Grade, Date of Concrete Test: 7/30/2015
Target Data: 84" OD, Briquet Compressive Strength: 6273 psi, Age of Target: 31 days

Shot No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
Clearence, in.	0.00	0.13	0.44	0.62	0.44	0.13	0.00	0.13	0.44	0.62
Casing Hole Diameter, Short Axis, in.	0.30	0.33	0.27	0.29	0.31	0.36	0.29	0.31	0.28	0.27
Casing Hole Diameter, Long Axis, in.	0.32	0.37	0.28	0.29	0.32	0.37	0.29	0.34	0.28	0.27
Average Casing Hole Diameter, in.	0.31	0.35	0.28	0.29	0.32	0.37	0.29	0.33	0.28	0.27
Total Depth, in.	32.55	29.14	28.98	26.41	28.75	32.30	30.18	33.85	28.64	31.31
Burr Height, in.	0.09	0.09	0.10	0.03	0.07	0.06	0.08	0.05	0.04	0.05

Shot No.	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18	No. 19	No. 20	Average
Clearence, in.	0.44	0.13	0.00	0.13							0.26
Casing Hole Diameter, Short Axis, in.	0.30	0.31	0.32	0.32							0.30
Casing Hole Diameter, Long Axis, in.	0.31	0.31	0.36	0.32							0.32
Average Casing Hole Diameter, in.	0.31	0.31	0.34	0.32							0.31
Total Depth, in.	28.65	32.25	31.13	27.35							30.11
Burr Height, in.	0.06	0.04	0.05	0.08							0.06

Remarks

SECTION 2 - BEREA SANDSTONE CORE TARGET

Berea Bulk Porosity, ___
Date of Berea Test ___

Shot No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	Average
Faceplate Hole Diameter, Short Axis, in.							
Faceplate Hole Diameter, Long Axis, in.							
Average Faceplate Hole Diameter, in.							
Total Depth, in.							

CERTIFICATION

Type of Certification: [X] Self [ ] Third Party

I certify that these tests were made according to the procedures as outlined in API RP 43: Recommended Practices for Evaluation of Well Perforators, Fifth Edition, January 1991. All of the equipment used in these tests, such as the guns, jet charges, detonator cord,etc., was standard with our company for use in the gun being tested, and was not changed in any manner for the test. Furthermore, the equipement was chosen at random from stock and therefore will be substantially the same as the equipement which would be furnished to perforate a well for any operator.

		(Company Officer)	(Title)	(Date)	(Company)	(Address)
	CERTIFIED BY	[signature]	VP Engineering	6/24/2016	GEODynamics, Inc.	10500 West Interstate 20, Millsap, Texas 76140
	RECERTIFIED					
X	PRELIMINARY					

9.7 Sample ID #7C/#8C/#17C - Conical Shaped Charge, large

API FORM 43F

CERTIFICATION DATA SHEET

PERFORATING SYSTEM EVALUATION, RP 43, SECTIONS 1 AND 2

3-3/8" EXPENDABLE, 6 SPF 60°

EC2-33B2522

Service Company: AVAILABLE TO ALL FROM GEODynamics, INC.
Gun OD & Trade Na: 3-3/8" EXPENDABLE, 6 SPF 60°
Charge Name: 3-3/8" GEOcmt XDP
Manufacturer Charge Part No.: EC2-33B2522 Date of Manufacture: 5/13/2005
Gun Type: SCALLOPED GUN (RETRIEVABLE, EXPENDABLE HOLLOW STEEL CARRIER)
Phasing Tested: 60 degrees, Firing Order X Top down, X Bottom up
Debris Description: SMALL STEEL PARTICLES MAY EXIT CARRIER
Remarks: GUNS MAY BE TUBING OR WIRELINE CONVEYED

Explosive Weight 25 gm, HMX powder, Case Material STEEL
Max. Temp, F 400 1 hr ___ 3 hr ___ 24 hr ___ 100 hr ___ hr
Maximum Pressure Rating 22,700 psi, Carrier Material STEEL
Shot Density 6 shots/ft
Recommended Minimum ID for Running 3.8 in.
Available Firing Mode X Selective, X Simultaneous.
Debris Weight N/A gm/charge, Debris N/A in.3/charge

SECTION 1 - CONCRETE TARGET

Casing Data 4-1/2" OD, Weight 11.6 lb/ft, L-80 API Grade, Date of Concrete Test 6/10/2005
Target Data 120 OD, Briquet Compressive Strength 7292 psi, Age of Target 29 days

Shot No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	
Clearence, in.	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	
Casing Hole Diameter, Short Axis, in.	0.48	0.50	0.47	0.49	0.46	0.44	0.43	0.44	0.46	0.45	
Casing Hole Diameter, Long Axis, in.	0.49	0.51	0.48	0.50	0.47	0.45	0.44	0.45	0.47	0.46	
Average Casing Hole Diameter, in.	0.49	0.51	0.48	0.50	0.47	0.45	0.44	0.45	0.47	0.46	
Total Depth, in.	49.20	45.70	48.90	46.80	50.40	48.30	49.40	51.40	43.60	50.20	
Burr Height, in.	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.04	0.05	0.06	
Shot No.	**No. 11**	**No. 12**	**No. 13**	**No. 14**	**No. 15**	**No. 16**	**No. 17**	**No. 18**	**No. 19**	**No. 20**	**Average**
Clearence, in.	0.31	0.31									0.31
Casing Hole Diameter, Short Axis, in.	0.44	0.46									0.46
Casing Hole Diameter, Long Axis, in.	0.45	0.47									0.47
Average Casing Hole Diameter, in.	0.45	0.47									0.47
Total Depth, in.	46.70	47.10									48.14
Burr Height, in.	0.05	0.04									0.05

Remarks: PENETRATION NORMALIZED TO 5000 PSI CONCRETE WOULD BE 53.65" (5% PER 1,000 PSI)

SECTION 2 - BEREA SANDSTONE CORE TARGET

Berea Bulk Porosity, ___
Date of Berea Test ___

Shot No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	Average
Faceplate Hole Diameter, Short Axis, in.							
Faceplate Hole Diameter, Long Axis, in.							
Average Faceplate Hole Diameter, in.							
Total Depth, in.							

CERTIFICATION

Type of Certification: [X] Self [ ] Third Party

I certify that these tests were made according to the procedures as outlined in API RP 43: Recommended Practices for Evaluation of Well Perforators, Fifth Edition, January 1991. All of the equipment used in these tests, such as the guns, jet charges, detonator cord,etc., was standard with our company for use in the gun being tested, and was not changed in any manner for the test. Furthermore, the equipement was chosen at random from stock and therefore will be substantially the same as the equipement which would be furnished to perforate a well for any operator.

		(Company Officer)	(Title)	(Date)	(Company)	(Address)
	CERTIFIED BY		C.E.O.	6/10/2005	GEODynamics, Inc.	10500 West Interstate 20, Millsap, Texas 76140
	RECERTIFIED					
X	PRELIMINARY					

9.8 Sample ID #9A - Detonating Cord, small

PRIMACORD®

Technical Information

BOOSTERS • CORDS

Detonating Cord

Properties SDS #1126

See Page 2 for PRIMACORD Detonating Cord properties

Product Description
PRIMACORD detonating cords are flexible linear explosives with a core of PETN explosive encased in a textile outer jacket. PRIMACORD detonating cords are designed for use as trunklines and/or downlines in various mining, quarrying and construction applications.

Application Recommendations
- ALWAYS cut detonating cord with a sharp, non-sparking knife.
- NEVER attempt to cut detonating cords by abrasion or with a blow from a sharp or blunt object.
- ALWAYS use square knots to extend/join detonating cords that will propagate self-to-self. When connecting downlines to trunklines, always use a clove hitch knot and keep incoming and outgoing cords at right angles to avoid possibility of cut-offs.
- NEVER join PRIMACORD 1, 2 and 3 together with knots because it will not propagate self-to-self.
- ALWAYS use a detonating cord product, such as PRIMACORD 4Y or 4R or detonating cord with a greater explosive coreload as a trunkline to initiate PRIMACORD 1, 2 or 3.
- ALWAYS use a double wrap clove hitch knot to connect PRIMACORD 1, 2 and 3 detonating cord to the trunkline cord.
- NEVER allow trunklines and/or downlines to cross.

- Minimum recommended initiating detonator is a No. 8 strength.
- Minimum recommended cord initiator is a 3.6 g/m (18 gr/ft) detonating cord, such as PRIMACORD 4Y or 4R, or another detonating cord with an equal or greater explosive coreload.

Transportation, Storage and Handling
- PRIMACORD must be transported, stored, handled and used in conformity with all federal, state, provincial and local laws and regulations.
- For maximum shelf life (5 years), PRIMACORD must be stored in a cool, dry, well ventilated magazine. Explosive inventory should be rotated. Avoid using new materials before the old. For recommended good practices in transporting, storing, handling and using this product, see the booklet "Prevention of Accidents in the Use of Explosive Materials" packed inside each case and the Safety Library publications of the Institute of Makers of Explosives.
- CE 0589

Hazardous Shipping Description
Cord, Detonating, 1.1D, UN 0065, II EX 1992020035

I-23-09-18-15

See Product Disclaimer on page 2

DYNO Dyno Nobel
Groundbreaking Performance

PRIMACORD®

Technical Information

Packaging

Part Number	Product	PETN Coreload (nominal)*		Outside Diameter*		Tensile Strength*		Color / Counter	Weight / Case*		Spools / case	Length / Spool*		Net Explosives Content* (NEC) / 1000 ft		Velocity of Detonation (minimum) m / sec
		g/m	gr/ft	mm	in	kg	lbs		kg	lbs		m	ft	kg	lbs	
A308033	PRIMACORD 1	1.5	7.5	3.18	0.13	68	150	Yellow / 5 Black	9	20	2	610	2000	0.51	1.07	6,300
A301042	PRIMACORD 2.5	2.4	12.5	2.8	0.11	27	60	Red / 4 Black	12	25	2	610	2000	0.81	1.79	6,300
A308033	PRIMACORD 3	3.2	15	3.66	0.14	113	250	Red / 5 Black	13	29	2	610	2000	1.02	2.14	6,700
A310033	PRIMACORD 4Y	3.6	18	3.61	0.14	68	150	Yellow / 2 Black	6	14	2	305	1000	1.22	2.57	6,700
A712033	PRIMACORD 4R*	3.6	18	3.61	0.14	68	150	Red	4	8	2	610	2000	1.22	2.57	6,700
A320035	PRIMACORD 5	5.3	25	3.99	0.16	68	150	Red / 1 Black	11	25	2	458	1500	1.70	3.57	6,700
A355030	PRIMACORD 8	8.5	40	4.47	0.18	90	200	Red / 2 Black	11	24	2	305	1000	2.72	5.72	6,700
A349030	PRIMACORD 10	10.6	50	4.70	0.19	90	200	Yellow / 2 Black	12	27	2	305	1000	3.40	7.15	6,700
A356030	PRIMACORD 10 SEISMIC	10.6	50	4.70	0.19	90	200	Yellow / White	12	27	2	305	1000	3.40	7.15	6,700

* All weights and dimensions are approximate

Notes: 1. Higher coreload detonating cords are available.
2. Alternative packaging is available for some products.

Please contact your Dyno Nobel representative for details.

Product Disclaimer Dyno Nobel Inc. and its subsidiaries disclaim any warranties with respect to this product, the safety or suitability thereof, or the results to be obtained, whether express or implied, INCLUDING WITHOUT LIMITATION, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE AND/OR OTHER WARRANTY. Buyers and users assume all risk, responsibility and liability whatsoever from any and all injuries (including death), losses, or damages to persons or property arising from the use of this product. Under no circumstances shall Dyno Nobel Inc. or any of its subsidiaries be liable for special, consequential or incidental damages or for anticipated loss of profits.

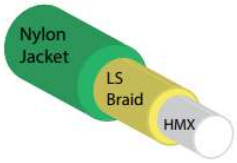
Dyno Nobel Inc.
2795 East Cottonwood Parkway, Suite 500, Salt Lake City, Utah 84121 USA
Phone 800-732-7534 Fax 801-328-6452 Web www.dynonobel.com

DYNO Dyno Nobel
Groundbreaking Performance

9.9 Sample ID #9B - Detonating Cord, medium

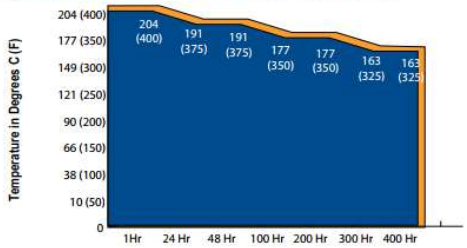
FireLine®
17/80 HMX LS
Oil Field Detonating Cord

Technical Information



Product Description
FIRELINE 17/80 HMX LS is designed to be used in carrier-based perforating systems within HMX time and temperature operating ranges, where the jacket is **protected or not exposed** to pressure and/or fluids. Tubing or wireline conveyed perforating systems shall be employed within time and temperature limits (see graph). Nylon jacket limitations will not normally permit this product to be used in exposed applications within HMX application ranges.

Temperature Range
The temperatures listed are maximum values. DO NOT EXCEED.



Properties SDS #1121

Explosive Core Load	17 g/m (80 gr/ft) nominal 15.3 g/m (72 gr/ft) minimum
Detonation Velocity	7500 m/s (24,600 ft/s) nominal 7000 m/s (22,960 ft/s) minimum
Shrinkage	1% maximum @ 163°C (325°F) in 24 hrs
Jacket Thickness	0.20 mm (0.008 in) minimum
Dimensions	5.33 mm (0.210 in) nominal ± 0.20 mm (0.008 in)
Lap Joint Sensitive	Yes
Product Code	A571010
Cord Components	HMX explosive core (white) Shrink resistant braid (yellow/gold) Nylon jacket (green)

- **Temperature resistance** is based upon the manufacturer's laboratory tests in air, at ambient pressure only.
- **Shrinkage** is defined as the overall decrease in length.
- **Velocity** was tested unconfined, at ambient pressure, and after "cool down."

Hazardous Shipping Description
Cord, Detonating, 1.1D, UN 0065 EX 1992020035

Alternative Packaging: FIREPAK® 1.4D air cargo shipping containers
Product Code A571015
Cord, Detonating, 1.4D UN 0289 EX 1995050048

S-09-08-06-15

See Product Disclaimer on page 2.

DYNO Dyno Nobel
Groundbreaking Performance

FireLine®
17/80 HMX LS

Technical Information

Transportation, Storage and Handling
- For maximum shelf-life, detonating cord must be stored in cool, dry, well-ventilated magazines. Explosives inventory should be rotated. Use older inventory first. Recommended shelf life, under proper storage conditions, is five (5) years from date of manufacture.
- FIRELINE 17/80 HMX LS detonating cords must be transported, stored, handled and used in conformity with all federal, state, provincial and local laws and regulations.

Application Recommendations
This product is not recommended for exposure to well bore fluids.
- ALWAYS cut FIRELINE 17/80 HMX LS detonating cord with a sharp knife.
- NEVER attempt to cut FIRELINE 17/80 HMX LS detonating cord with a blow from a sharp or blunt object, such as an axe, pipe wrench, or rock.
- NEVER saw FIRELINE 17/80 HMX LS detonating cord; it may explode and kill or injure.
- NEVER cut detonating cord with devices that produce metal-to-metal contact, such as scissors, wire cutters, crimpers or similar instruments.

Packaging

Package	Gross Weight*		Net Weight*		Explosive Weight*		Spools/ Case	Length/ Spool**	
	kg	lbs	kg	lbs	kg	lbs		m	ft
Fiberboard box	5.1	11.2	4.9	10.7	2.6	5.7	1	152	500
Airpack box	17.9	39.5	4.9	10.7	2.6	5.7	1	152	500

- Weights represent nominal values.
* All weights are approximate.
**±2%; 152m spools may contain as many as 3 pieces, totally 152 m, with a minimum splice/piece length of 8 m (25 ft).

X-ray services are also available for high profile applications requiring an extra level of assurance. Product Code A571011 (1.1D) & A571016 (1.4D).

For 1.1D Detonating Cord marked every meter, use Product Code A571010BZ
For 1.4D Detonating Cord marked every meter, use Product Code A571015BZ

CE0519 ENB/C/021/06

Case Dimensions
Fiberboard: 26 x 26 x 14 cm / 10.25 x 10.25 x 5.5 in
Airpack: 74.3 x 44.1 x 68.27 cm / 29.25 x 17.375 x 26.875 in

Dyno Nobel
2795 East Cottonwood Parkway Suite 500, Salt Lake City, Utah 84121 USA
Phone 800-732-7534 Fax 801-328-6452 Web www.dynonobel.com

DYNO Dyno Nobel
Groundbreaking Performance

9.10 Sample ID #14B - Fuze, medium

SN Technologies S.A.	PYROTECHNICAL SAFETY DATA SHEET Class 1 explosive materials or objects	Ref: C.R / MSTA Index: Rev. C - Date: 28.02.13

1 – IDENTIFICATION OF THE PRODUCT AND THE COMPANY

F985 C fuse, detonator with safety device (circumstance conditioning).

Company SN Technologies S.A. Rue Pré-de-la Fontaine 19 CH-1217 MEYRIN 1 / SUISSE	+ 41 22 989 12 90 (Office time) snt.robert@bluewin.ch, snt.giannasi@bluewin.ch

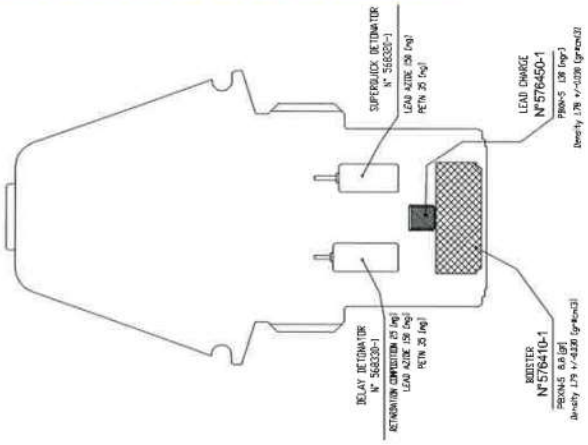
2 - IDENTIFICATION OF HAZARDS complete fuse level

Risk division / compatibility group	Packaged / unpackaged:	1.2 D 1 for packaging in wooden box
	unpackaged	packaged
- Pyrotechnical: 	Explosion in the event of a fire, shock or friction or other sources of ignition. Projections of metallic parts in a radius of 400 [m]	Explosion in the event of a fire, shock or friction or other sources of ignition. Projections of metallic parts in a radius of 400 [m]
- Other hazards:	Nitrous fume in case of fire	Nitrous fume in case of fire

3 – CHARACTERISTICS OF THE MATERIAL OR THE OBJECT

Electromechanical PD fuse for 120 mm IM HE-T ammunition

Arrangement of pyrotechnical components " F985 C Explosive Chain"



Active substances :

1) **ELEC. DETONATION CAP 568 320-1:**
- ~150 [mg] lead azide
- ~35 [mg] penthrite

2) **DELAY ELEC. DETONATION CAP 568 330-1 :**
- ~ 25 [mg] delay composition
- ~150 [mg] lead azide
- ~35 [mg] penthrite

3) **LEAD CHARGE PBX-N5 576450-1 :** ~ 130 [mg] PBX-N5

4) **BOOSTER PBX-N5 576410-1 :** ~ 8.8 [gr] PBX-N5

Total Mass Active Substance: ~ 9, 325 [gr]

9.11 Sample ID #15C - Rocket Motor, large

AEROTECH F32T

CERTIFIED VALUES

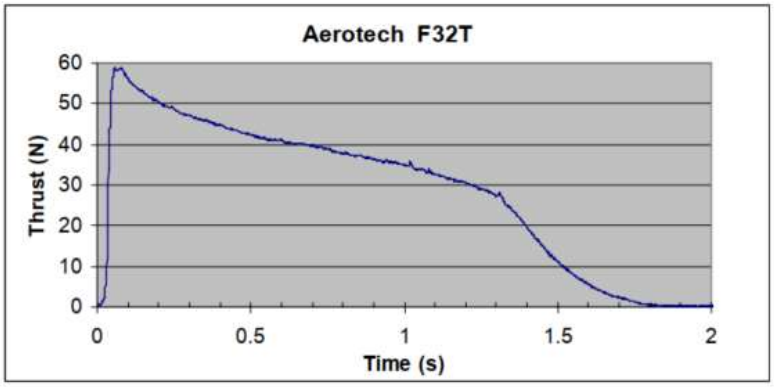
Total Impulse:	56.9 Newton-seconds
Delays:	4, 6, 8 seconds
Propellant Type:	Blue Thunder
Propellant Mass:	25.8 grams
Casing Dimensions:	24mm × 90mm
Certification Date:	Janunary 14, 2009
Certification Type:	Model Rocket Motor

STATIC TEST DATA

Date Tested:	January 11, 2009	
Total Impulse:	56.9 Newton-seconds	(σ 0.73)
Peak Thrust:	61.3 Newtons	(σ 4.3)
Burn Time:	1.659 seconds	(σ 0.061)
Average Thrust:	34.1 Newtons	(σ 1.0
Mass After Firing:	33 grams	

Delay Time(sec.)	8	6	4
Average Measured Delay(sec.)	8.77	5.55	3.69
Initial Mass (gm.)	65	64	64

TYPICAL THRUST-TIME CURVE



REMARKS

Updated: January 14, 2009

Data File #	Engine	Total Impulse	Max Thrust	Avg. Thrust	Burn Time	Delay Time	Initial Weight	Fired Weight
090110W01	F32-4T	56.9	59.3	34.2	1.657	3.97	64	33
090110W02	F32-4T	57.4	57.6	33.3	1.715	3.92	64	33
090110W03	F32-4T	56.9	60.4	33.9	1.674	3.79	65	33
090110W04	F32-4T	57.9	65.0	33.2	1.735	3.09	64	33
090110W05	F32-6T	56.5	59.1	33.8	1.663	5.27	64	33
090110W06	F32-6T	55.7	62.5	34.1	1.626	5.15	64	33
090110W07	F32-6T	56.1	71.4	35.3	1.582	6.35	64	33
090110W08	F32-6T	57.7	57.7	34.7	1.656	5.42	65	33
090110W09	F32-8T	57.2	64.5	32.7	1.739	8.36	65	33
090110W10	F32-8T	57.6	59.4	33.9	1.664	8.89	65	33
090110W11	F32-8T	56.1	57.6	36.3	1.539	9.05	65	33
Average		56.90	61.3	34.1	1.659		64	33
Std Dev		0.734	4.257	1.014	0.061			
Std Dev %		1.3%	6.9%	3.0%	3.7%			

Range	Indicated	Actual	Actual	Actual	Actual	Average
4	2.5 to 5.5	3.97	3.92	3.79	3.09	3.69
6	4.5 to 7.5	5.27	5.15	6.35	5.42	5.55
8	6.4 to 9.6	8.36	8.89	9.05		8.77

; @File: F32T.txt, @Pts-I: 1501, @Pts-O: 32, @Sm: 3, @CO: 5%
; @TI: 56.7109, @TIa: 56.4715, @TIe: 0.0%, @ThMax: 58.525, @ThAvg: 34.2667, @Tb: 1.648
; Exported using ThrustCurveTool, www.ThrustGear.com
F32 24 90 4 6 8 0.0258 0.064 Aerotech/RCS
0.0 0.00669778
0.17 0.236738
0.192 0.794052
0.202 2.68628
0.204 3.57052
0.208 7.96887
0.21 11.79011
0.212 16.82641
0.22 39.2314
0.224 46.779
0.228 51.8968
0.232 55.296
0.236 56.9612
0.258 58.4048
0.288 55.2426
0.316 53.4728
0.394 49.5892
0.458 47.4002
0.73 41.2237
0.904 39.3815
1.11 35.6689
1.198 35.0946
1.22 33.8331
1.2599 33.5013
1.4779 27.3792
1.4899 27.7527
1.5099 25.4378
1.6759 11.26592
1.7679 5.94688
1.8519 2.91383
1.9519 0.745781
2.0639 0.0

Updated: January 14, 2009