A-P-T RESEARCH, INC.
AN EMPLOYEE-OWNED COMPANY

FINE GRAIN METAL POWDER STANDARDS FOR CONSUMER PYROTECHNICS

FINAL REPORT

Contract #: 693JK320C000006

Final Report
CDTS-AL003-22-00400
October 2022

Fine Grain Metal Powder Standards for Consumer Pyrotechnics

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ACRONYMS

AFSL	American Fireworks Safety Laboratory
AGL	Above Ground Level
APA	American Pyrotechnic Association
APT	A-P-T Research, Inc.
BNC	Berkeley Nucleonics Corp
COR	Contracting Officer's Representative
CFR	Code of Federal Regulations
CPSC	Consumer Product Safety Commission
DOE	Design of Experiments
DOT	Department of Transportation
FGMP	Fine Grain Metal Powder
HD	Hazard Division
OSU	Oklahoma State University
PHMSA	Pipeline and Hazardous Materials Safety Administration
RSO	Range/Safety Officer
R&D	Research and Development
SEAC	Safety Engineering and Analysis Center
SME	Subject Matter Expert
SOP	Standard Operating Procedure
SOW	Statement of Work
UN	United Nations

PART I: INTRODUCTION

1.0 Executive Summary

Under contract with the Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA), A-P-T Research, Inc. (APT) conducted research and testing in support of PHMSA's safety mission by studying a variety of percentages of metal powders (a.k.a. Fine Grain Metal Powders (FGMP)) in pyrotechnic compositions (specifically in burst charges) to identify the potential safety impacts on hazard classification when changing the concentration of the metal powders. The results of this effort provide test data and analysis which both the consumer and PHMSA can utilize in the decision-making process regarding hazard classification.

In accordance with the Statement of Work (SOW) for DOT PHMSA contract number 693JK320C000006 there were four phases of the contract under the SOW APT was tasked to:

1. *Kick-off Phase*: Hold a kick-off meeting to review the project expectations, project management, and administration of the project with the PHMSA Contracting Officer's Representative (COR). A project schedule was prepared and delivered.
2. *Research Phase*: Complete a literature review of current standards. APT was tasked with reviewing existing classification standards in the American Pyrotechnics Association (APA) 87-1 and selecting up to twenty existing pyrotechnic burst charge mixtures for testing. Those items selected for testing were selected from existing pyrotechnic materials used as burst charges in consumer, display, and theatrical pyrotechnics, with varying amounts of FGMP. APT researched the pyrotechnic materials commonly used in consumer, theatrical and display pyrotechnic burst charges to identify which materials should be included in testing. APT also identified the percentages of fine mesh metal powders to vary during testing. APT performed a Design of Experiments (DOE) to determine the optimal mix of samples and combinations to obtain statistically significant results. To determine appropriate testing, APT reviewed applicable regulations, including those in the 49 CFR 173.56, the APA 87-1, and the UN Manual of Tests and Criteria. Based on the findings of the review, APT developed a proof of concept to be used to confirm tests and criteria that are needed to establish FGMP concentration thresholds at which these explosives shall effectively transition from Hazard Division (HD) 1.4 to HD 1.3. A report outlining the findings of literature review was delivered.
3. *Testing Phase*: Identify and characterize the explosive effects from varying fine mesh metal powder percentages in consumer pyrotechnic burst charges, with the goal of identifying whether there are acceptable concentration thresholds based upon factors of safety and transportation configurations. In order to accomplish this APT performed functional testing on existing pyrotechnic compositions commonly used in burst charges. Each of the existing consumer pyrotechnic compositions were tested to establish a

baseline. Variations of each were then tested by introducing fine mesh metal powders into the compositions ranging from 3% to 12% of the total volume of fine mesh metal powder. The testing was conducted to measure variations in air burst overpressure, and to differentiate among explosive, partial detonation, and detonation reactions. A test report summarizing the explosive effects of different percentages was delivered to DOT.

4. *Final Reporting Phase*: Develop and submit a final report to include all findings, recommendations and adopted suggestions surrounding the classification of fine mesh metal powders outlined in the three previous tasks.

The FGMP findings did not provide sufficient justification for adopting any revisions to current regulation or standards. However, the findings do provide justification that adopting revisions to the current regulations or standards could be recommended once comprehensive testing provides additional favorable data.

2.0 Problem Overview

Fine mesh metal powder is commonly used in fireworks burst charges for two reasons: (1) to produce a particular sound, and (2) because a metal such as aluminum contributes to the symmetry of visual effect detonations. Metallic fuels used in a burst charge produce a different sound during detonation than a black powder-only burst charge device due to the pressure wave that a metallic fuel produces. Specifically, fireworks using metallic fuels as burst charges with metal particles below 100 mesh size have greater explosive force per volume of pyrotechnic material than fireworks using only black powder or coarser (larger than 100 mesh) metal powders.

3.0 Project Scope

As stated in the contract statement of work the scope of this project was to provide additional test data that both the consumer and PHMSA could utilize in the decision-making process regarding hazard classification. Without this study to provide evidence-based data on the explosive effects of including fine mesh metal powders in consumer pyrotechnic burst charges, data would not exist to support an informed decision on whether regulations should/could be changed.

4.0 Report Scope

This final report is the fourth of four deliverables for this contract. It includes all findings, recommendations and adopted suggestions surrounding the classification of fine mesh metal powders outlined in the previous tasks. The previous three phases and deliverables of the contract are also summarized in this report: kick-off phase, research phase, and testing phase.

PART II: PHASE 1 – KICK-OFF

5.0 Kick-off Phase Summary

A kick-off meeting between PHMSA and APT was held on 28 October 2020. The objective of the meeting was to develop a clear understanding regarding the scope and project phases of the contract and gain a consensus among PHMSA and APT. Technical leads for the government and contractor were established to ensure open lines of communication and points of contact for future questions and discussions. It was reported that the contract would be managed by the Safety Engineering and Analysis Center (SEAC) Division of APT. The SEAC has completed multiple Research and Development (R&D) efforts for PHMSA and also had some ongoing PHMSA R&D projects. The SEAC personnel that would be supporting the FGMP contract were identified. At the time of the kick-off meeting APT was still assessing quotes from potential subcontracting teammates who would support the test phase. APT presented the overall project plan and timeline and discussed how the monthly reporting would provide an update on activities, progress towards milestones and any issues or concerns that may arise. The program plan that was presented at the kick-off meeting was updated throughout the period of performance of the contract and resubmitted to PHMSA as needed.

PART III: PHASE 2 – RESEARCH

6.0 Research Phase Summary

The purpose of Phase 2 was to conduct research in support of PHMSA's safety mission by performing a study on a variety of particle sizes of metal powders (a.k.a. FGMP) in pyrotechnic compositions (specifically in burst charges) to identify the potential safety impacts on hazard classification when changing the size and concentration of the metal powders. Based on research and discussions held with the American Pyrotechnic Association (APA), American Fireworks Safety Laboratory (AFSL) and multiple pyrotechnic manufacturers, APT worked to identify the percent thresholds and metal sizes for inclusion in testing of potential consumer fireworks. A research report was also developed during this phase and was the second of four deliverables for this contract.

The research report focused on the burst charge portion of a pyrotechnic. As defined in APA-87-1, a burst charge is:

> *"Burst Charge Chemical composition used to break open a fireworks device after it has been propelled into the air, producing a secondary effect such as a shower of stars. Burst charge is also sometimes referred to as expelling charge or break charge. Any burst charge containing metallic powder (such as magnalium or aluminum) less than 100 mesh in particle size, is considered to be intended to produce an audible effect and is limited to 130 mg in 1.4G fireworks devices. Burst charge consisting of black powder or equivalent*

> *non-metallic composition is not considered to be intended to produce an audible effect when it is used to expel and ignite a secondary effect in a fireworks device. Burst charge for use in 1.3G fireworks is limited to black powder (potassium nitrate, sulfur, and charcoal) or similar pyrotechnic composition without metallic fuel for approval under the provisions of this standard"*

The report compiled the research of the pyrotechnic materials commonly used in consumer, theatrical and display pyrotechnic burst charges. Recommendations of which materials should be used in the project were also included. The research report also identified the percentages, mesh sizes, and morphology of fine mesh metal powders that would be used during testing.

Following the identification of pyrotechnic items, a DOE was developed to determine the optimal mix of samples and combinations to obtain statistically significant results. review applicable regulations, including those in the 49 Code of Federal Regulations (CFR) 173.56, the APA 87-1, and the United Nations (UN) Manual of Tests and Criteria.

7.0 Current Regulation Under Review

According to Title 49 CFR § 173.65 (a) HD 1.4G consumer pyrotechnics may be offered for transportation provided: (1) the fireworks are manufactured in accordance with the applicable requirements in APA Standard 87-1, and (2) the device passes a thermal stability test[1].

One of the differences among consumer pyrotechnics and theatrical or display pyrotechnics is that, per APA Standard 87-1, burst charges in consumer pyrotechnics cannot contain fine mesh metal powders. This is consistent between the existing version of APA Standard 87-1 and the proposed revisions that are pending final adoption by PHMSA.

7.1 QUESTIONING IF THE CURRENT REGULATIONS CAN BE RELAXED

Many fireworks manufacturers have shifted to the use of pyrotechnic materials that contain metallic fuels to produce the sharp, clear audible effects in aerial devices. As a result, several consumer fireworks importers/retailers have recently requested that PHMSA and APA Standard 87-1 relax the restriction for fine mesh metal powders in burst charges.

During an October 2018 Consumer Product Safety Commission (CPSC) rulemaking session, it was suggested that a consumer pyrotechnic burst charge could contain up to 15% fine mesh metal powder in the burst charge without any impact on safety. Several attendees advocated for a change in the PHMSA rules and in APA Standard 87-1[2] to reflect the higher powder percentage.

Currently federal regulations and APA Standards restrict the use of FGMP fuels (aluminum and magnalium) to larger than 149 micron and not to exceed 10% of total weight of the burst charge

[1] There was no thermal stability testing done on the custom devices, as they were produced for R&D purposes for this project only.

[2] U.S. Consumer Product Safety Commission. "Fireworks Final Rule Briefing Package, Final Rule to Revise Current Fireworks Regulations," (September 26, 2018)

formulation or propellant formulation in consumer fireworks. Additionally, the use of powders with grain sizes between 53 and 149 microns is not permitted. The issue is that, in general, the more surface area of a pyrotechnic material that can be engaged in a reaction, the more efficient and energetic the combustion effect will be. The finer the mesh size of an energetic material, the smaller the particle size and the more particles that can fit into any given volume the more energetic the reaction. For illustration, consider the difference in surface areas of a basketball in a bucket versus the same bucket filled with golf balls. The surface area of all of the golf balls combined will be much greater.

Another factor to keep in mind when considering surface area is particle morphology or shape. For example, a spherical metal particle below 100 mesh is much less sensitive to stimuli than a particle of the same size but of ‘flake’ type morphology. For instance, Figure 1 shows the physical difference between aluminum powder and aluminum flake, both of which are used in pyrotechnics. The latter has much more surface area than the spherical example and is a factor that must considered when designing pyrotechnic mixtures. For example, RDX (1,3,5-trinitro-1,3,5-triazine) particles with a spheroidal shape with a smoothened surface have less shock sensitivity than facetted particles. As another example, aluminum powder is typically less sensitive to reaction than aluminum flake. This was significant to the study since, as particle sizes are reduced, some energetic materials experience increased variability with regard to the morphology of the particles. This can translate into increased variability and reduced predictability of the explosive effect.

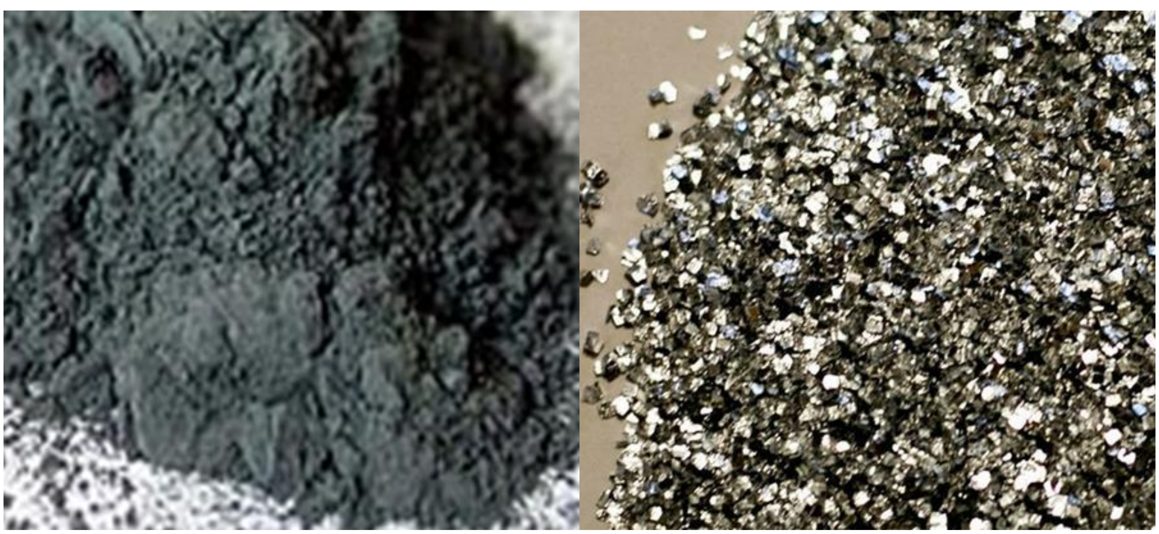

Figure 1: Aluminum Powder vs. Aluminum Flake

8.0 Research

Research performed for this effort focused on examination of current standards and accident history involving consumer pyrotechnics. Initially, the team looked at commonly used fireworks purchased by consumers.

Current Standards: Following a decade of work by the American Pyrotechnic Association, specifically the APA Standards Committee coordinating their efforts with the appropriate Congressional committee staff, APA Standard Final Rule 87-1 was published in the Federal Register on 28 November 2020 and became effective on 28 December 2020. Standard 87-1 revised and updated the voluntary fireworks classification standards used by the industry. This created three separate standards for Consumer Fireworks, Display Fireworks, and Entertainment and Technical Pyrotechnics 87-1A, 87-1B and 87-1C.

APA Standard 87-1A is the new voluntary standard for the consumer fireworks industry. Appendix I of the new standard lists permitted and restricted chemicals for consumer fireworks and novelties. Aluminum and Magnalium are metal powders used as fuels in fireworks and other pyrotechnic devices, and both have the same restrictions on their use under Standard 87-1A. The restrictions listed are as follows.

- Powders with a grain size greater than 149 microns (100 mesh) are not to exceed 10% by weight in a burst charge formulation or a propellant formulation.
- Powders with a grain size of 53 – 149 microns are not permitted in burst charges.
- Powders with a grain size of less than 53 microns may only be used in reports and are limited to 153 grams in weight. (Reports are audible effects in a firework device)

Appendix VI of APA Standard 87-1A, entitled Specific Requirements Pertaining to the Consumer Product Safety Commission, stated that the burst charge for a consumer firework shall be black powder or equivalent non-metallic composition. Also, it is not considered to be an audible effect when the primary use is to expel and ignite a secondary effect in a consumer fireworks device (i.e., a break charge).

Accident History: A review was conducted of the most recent Consumer Product Safety Commission (CPSC) Fireworks Annual Report: Fireworks-Related Deaths, Emergency Department-Treated Injuries, and Enforcement Activities During 2019. Highlights of the report are as follows:

- CPSC staff received reports of twelve non-occupational, fireworks-related deaths during 2019. Seven of the deaths were associated with misuse of fireworks, two deaths were associated with fireworks device malfunction (late ignition), and three incidents were associated with unknown circumstances. Reporting of fireworks-related deaths for 2019 is not complete, and the number of deaths in 2019 should be considered a minimum.
- Fireworks were involved with an estimated 10,000 injuries treated in U.S. hospital emergency departments during calendar year 2019 (95 percent confidence interval 7,100 – 12,900). The estimated rate of fireworks-related, emergency department-treated injuries in the United States is 3.1 per 100,000 individuals.
- There is not a statistically significant trend in estimated emergency department-treated, fireworks- related injuries from 2004-2019.

- An estimated 7,300 fireworks-related injuries (or 73% of the total estimated fireworks-related injuries in 2019) were treated in U.S. hospital emergency departments during the one-month special study period between 21 June 2019, and 21 July 2019 (95% confidence interval 4,700 - 9,900).

9.0 Meetings with Domestic Manufacturers

APT began initiating contact with domestic manufacturers and importers of fireworks in early 2021, to discuss and identify potential items for use in the testing for the project. Decisions on which companies to contact were made in consultation with APA, the AFSL and government agencies familiar with the regulatory and professional history of companies in the fireworks industry. In an effort to determine if the companies were in position to assist in the project, the following background questions were asked by APT of the company representatives:

- Does your company do fireworks production on site?
- Do you have the ability to produce one-offs? (Looking for up to 20 mixtures/devices for testing.)
- Do you have access to different burst charge mixtures?
- Are you willing to participate?
- Are there any issues you can identify that would cause difficulties in doing so?

As a result of this research, a number of companies were identified which could produce or supply a wide variety of existing consumer fireworks submissions for testing. A lesser number of those companies indicated that their business included production of fireworks (not just in business as an importer). A still smaller number of companies indicated that they were involved in the production of both consumer and display fireworks (providing simplified access to burst charge mixtures for display fireworks, which are permitted to include fine grain metal powders).

From these contacts, four companies were identified as sources for the consumer firework devices and included a mix of pre-loaded and reloadable shell and cannister devices. These companies were TNT Fireworks, Phantom Fireworks, Winco Fireworks and Fireworks Over America. Two other companies, AM Pyro and Starfire Fireworks, were identified as companies that could produce the custom devices containing the break charge mixtures from display fireworks in consumer firework configurations. Both company owners are long time industry members with excellent reputations for safety and regulatory compliance. One of the owners is also a newly appointed member of the AFSL Standards Board.

APT hosted a meeting with APA and AFSL to review the list of potential pyrotechnics identified for testing. APT asked both APA and AFSL if there were any specific items to test of particular interest that would contribute to the success of the goals of this project. A list of pyrotechnic products was provided to both organizations for concurrence as items used for test purposes. APT also held conversations with pyrotechnic manufacturers and identified four companies (Figure 2) that would agree to provide materials to this project for use in the test phase. From this, the manufacturers could produce the alternate burst charge configurations necessary to compare the eblast effects from the differing fine grain components of the burst charge.

Figure 2: Pyrotechnic Manufacturers Who Could Potentially Provide Materials for Test Phase

APT hosted a meeting with DOT PHMSA to discuss the following specifics:

- Pyrotechnic selection
- DOE
- Testing/test site

APT personnel discussed each of the talking points to include discussions held with APA and ASFL. Concurrence was given by PHMSA to proceed forward with the next steps as presented.

10.0 Design of Experiments

During the research phase and preparation of the second deliverable of this contract, the APT team developed a design of experiments to determine the best path forward to garner the data and test results necessary to substantiate known values and to demonstrate other findings. The DOE, shown in Figure 3, displays the tests, the necessary inputs, and the levels for which each test would measure.

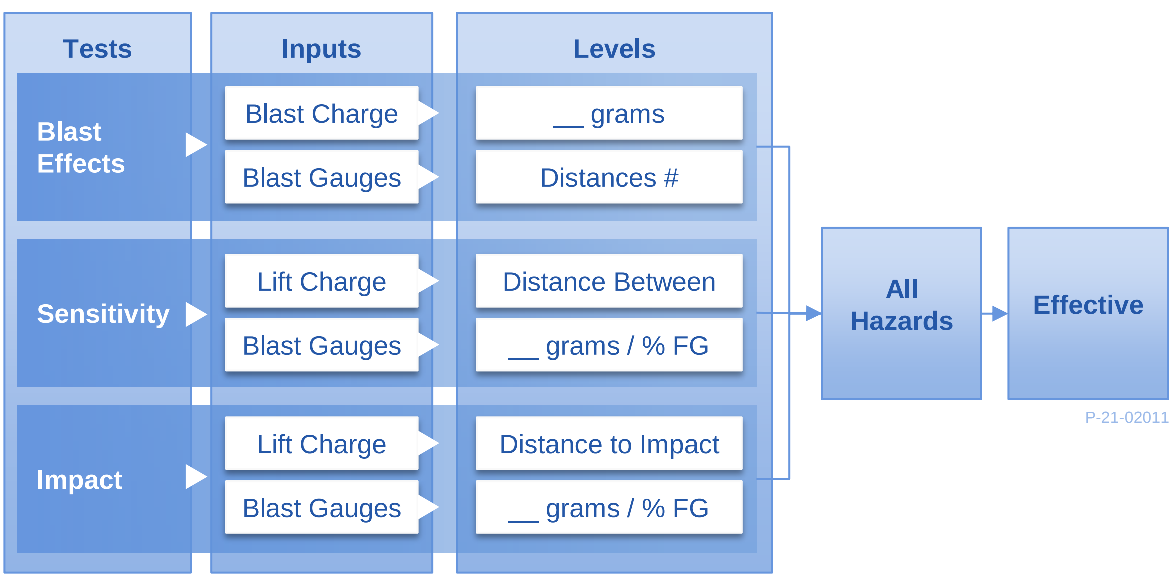

Figure 3. Design of Experiments (as Defined in Research Phase)

PART IV: PHASE 3 – TESTING

Phase 3 included both the testing of commercially available pyrotechnic products and custom shells that were manufactured for testing purposes only and the development of a test report. The test report was the third of four deliverables for this contract. The test report identified and characterized the explosive effects from varying fine mesh metal powder percentages in consumer pyrotechnic burst charges, with the goal of identifying whether there are acceptable concentration thresholds based upon factors of safety and transportation configurations. APT performed functional testing on existing pyrotechnic articles with currently approved compositions used in burst charges. A variety of existing consumer pyrotechnic devices were tested to establish a baseline. APT contracted with a licensed manufacturer to create custom devices with fine grain metal powders into the compositions in percentages ranging from 3% to 12% (of the total volume of the burst charge). The testing was conducted to document variations in blast overpressure, and to determine if the presence of the varying FGMP percentages affected the devices' sensitivity to external heat, pressure or impact.

Prior to the delivery of the test report a test plan which documented the tests that would be conducted and items to be tested was coordinated and reviewed by PMSHA. The test plan was not a contract deliverable.

11.0 Revision to Design of Experiments

Before testing started, the decision was made to eliminate the blast gauge portion for the sensitivity and impact tests, which resulted in a change to the original DOE. The DOE that was used for testing is shown in Figure 4.

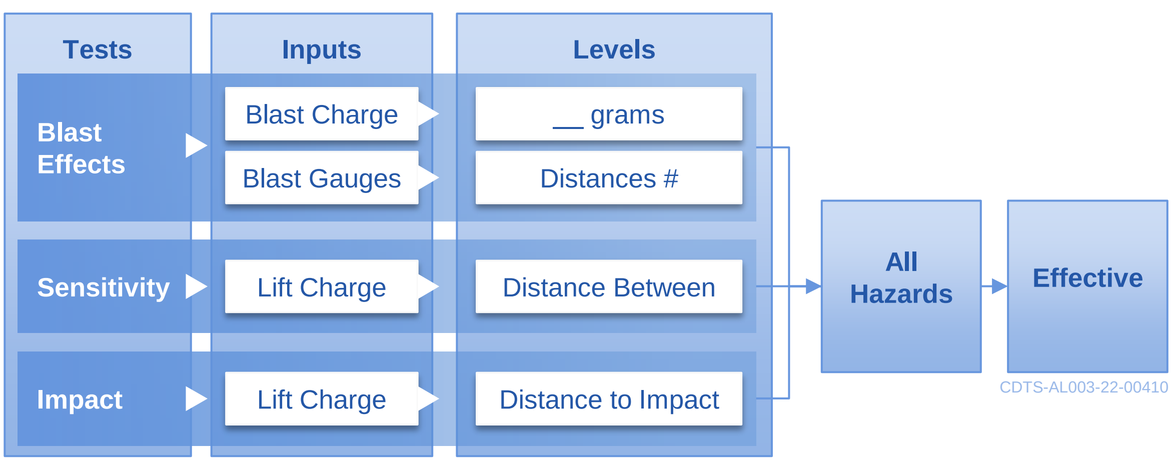

Figure 4. Design of Experiments (Used in Testing)

12.0 Test Site

APT subcontracted with Oklahoma State University's (OSU) Center for Health Sciences to perform testing at its Explosives Research and Testing Range located in Pawnee, Oklahoma. The testing was conducted in two sessions. The first testing session which started on 17 May 2022 and concluded on 20 May 2022, included sensitivity and impact tests. The second testing session which started on 27 June 2022 and concluded on 29 June 2022, included the overpressure tests. All these tests were conducted at an outdoor facility so the weather conditions during each session are noted below for reference. Tests were conducted during daylight hours when temperatures were on the higher side of the data provided below. Table 1 documents the weather conditions during the first session of testing and

Table 2 documents the weather conditions during the second session of testing.

Table 1. Weather Conditions During Testing – Session 1

Date	High Temperature[3] (Fahrenheit)	Low Temperature (Fahrenheit)	Rain[4] (inches)
16 May 2022	83	59	0
17 May 2022	85	63	0
18 May 2022	91	68	0
19 May 2022	89	65	0
20 May 2022	80	68	0

Table 2. Weather Conditions During Testing – Session 2

Date	High Temperature (Fahrenheit)	Low Temperature (Fahrenheit)	Rain (inches)
27 June 2022	83	63	0
28 June 2022	88	66	0
29 June 2022	91	61	0

12.1 TEST OBJECTIVE

The test plan outlined by APT was designed to provide the rationale for upholding the current prohibition against their use or support recommendations of acceptable limits for their inclusion.

12.2 FIRING SYSTEM AND CHARGE(S)

The firing system was controlled with a Berkeley Nucleonics Corp (BNC) 508 Current Pulse Generator firing system. Electric matches were used as initiators. For Test 1 (blast overpressure),

[3] Source for both High & Low Temperature Data: Weather Channel Almanac; https://weather.com/weather/monthly/l/5848b70431b10023d5e72cfb5df32ba1044c3b1e5f737f125bdc9e8b4da0b60e
[4] Source for Rain Data: National Centers for Environmental Information; https://www.ncdc.noaa.gov/cdo-web/search

the electric match was tied to the fuse that protruded from the shell (OSU removed the lift charges on these shells). For Test 2 (sensitivity), the electric match was attached to the fuse from a lift charge, which was placed in intimate contact with the subject shell. For Test 3 (impact), the electric match was tied to the fuse protruding from the complete device (lift charge attached to shell).

12.3 PRECAUTIONS AND RANGE SAFETY

The Range/Safety Officer (RSO) was responsible for controlling all firing operations. After each shot the RSO conducted a visual inspection of the test area and the overall range to determine the next course of action. If there would have been a misfire, the RSO would have been responsible for overseeing the procedures from the appropriate Standard Operating Procedure (SOP). If it was determined that there was uninitiated product that needed to be disposed of or retrieved, the RSO would have designated personnel to go down range equipped with any required personal protective equipment.

13.0 Test Articles

There were a total of seventeen commercially available pyrotechnic products that were selected for testing from four different companies. At least three of each product were provided, one for each test: blast effects testing, sensitivity testing and impact testing. Table 3 shows the list of the commercially available pyrotechnic products. In order to maintain the anonymity of the company the type (retail name) of each product was given a non-specific name in this report. All of the products shown in Table 3 are commercially available pyrotechnic products, have gone through hazard classification testing and meet the guidelines for transportation identified in APA Standard 87-1.

Table 3. Commercially Available Pyrotechnic Products

Commercially Available Product from Company 1 – Product 1 (C1P1)
Commercially Available Product from Company 1 – Product 2 (C1P2)
Commercially Available Product from Company 1 – Product 3 (C1P3)
Commercially Available Product from Company 2 – Product 1 (C2P1)
Commercially Available Product from Company 2 – Product 2 (C2P2)
Commercially Available Product from Company 2 – Product 3 (C2P3)
Commercially Available Product from Company 2 – Product 4 (C2P4)
Commercially Available Product from Company 2 – Product 5 (C2P5)
Commercially Available Product from Company 3 – Product 1 (C3P1)
Commercially Available Product from Company 3 – Product 2 (C3P2)
Commercially Available Product from Company 3 – Product 3 (C3P3)
Commercially Available Product from Company 3 – Product 4 (C3P4)
Commercially Available Product from Company 3 – Product 5 (C3P5)

Commercially Available Product from Company 4 – Product 1 (C4P1)
Commercially Available Product from Company 4 – Product 2 (C4P2)
Commercially Available Product from Company 4 – Product 3 (C4P3)
Commercially Available Product from Company 4 – Product 4 (C4P4)

In addition to the commercially available pyrotechnic products shown in Table 3, custom shells were manufactured for testing purposes. The strategy for testing was to compare commercially available pyrotechnic articles to the custom shells. These custom shells used the same consumer pyrotechnic article configurations, but with burst charges containing varying percentages and mesh sizes of fine grain metal powders. The custom shells were manufactured with four different percentages (12%, 9%, 6%, and 3%) of FGMP in the burst charges. A total of 200 custom shells were manufactured. Shells 1–40 were designated for use in blast effects testing, shells 41-120 were designated for use in sensitivity testing, and shells 121-200 were designated for use in impact testing. A complete listing of the shells is shown in Appendix B.

APT procured these custom shells from Pyrotechnique by Grucci, Inc[5]. They include:

- Sixty custom devices were manufactured with 12% of FGMP in the burst charge and they are identified as Grucci Custom 12%. Shells 1-12, 41-64, and 121-144 contain 12% FGMP.
- Sixty custom devices were manufactured with 9% of FGMP in the burst charge and they are identified as Grucci Custom 9%. Shells 13-24, 65-88, and 145-168 contain 9% FGMP.
- Forty custom devices were manufactured with 6% of FGMP in the burst charge and they are identified as Grucci Custom 6%. Shells 25-32, 89-104, and 169-184 contain 6% FGMP.
- Forty custom devices were manufactured with 3% of FGMP in the burst charge and they are identified as Grucci Custom 3%. Shells 33-40, 105-120, and 185-200 contain 3% FGMP.

14.0 Test Methods

To determine the data and analysis necessary for measuring the pressures and effects from initiation of the burst charges, blasts effects testing, sensitivity testing, and impact testing is required. For each of these types of tests the paragraphs below provide a description and the reasoning for why that specific test was conducted.

[5] Although not identified during the research phase as a potential source for the custom shells. During procurement this company was able to supply the needed products for testing within the constraints of schedule and budget.

14.1 BLAST EFFECTS TESTING

Initiation of the pyrotechnic shell by its own means of initiation (presumably, by delay/time fuse), measuring the blast effects with air blast gauges. This testing will provide comparison measurements of the blast effects of existing consumer devices against those of the custom devices which will include the FGMP in the burst charges.

14.1.1 Scope

This test assesses blast overpressure effects of a shell which includes a burst charge with varying percentages of FGMP. It is generally understood that mixtures containing FGMP are more energetic, and it was expected that the measurements of the custom device blast overpressures would bear that out. The comparison between the standard consumer devices and the custom devices with the FGMP in the burst charges can provide decision makers with additional information in determining whether to make changes to the current regulations on consumer device construction related to the use of FGMP.

14.1.2 Procedure

For this test the burst charges were initiated, and peak overpressure was captured at various distances. The sensors shown in Figure 5 used in this test are the Black Box Blast Gauges which can measure overpressure from 0.5-110psi with a resolution of 0.05psi and acceleration up to 200g per axis. These sensors are portable and designed to mount on soldiers and breachers for immediate feedback on blast exposure.

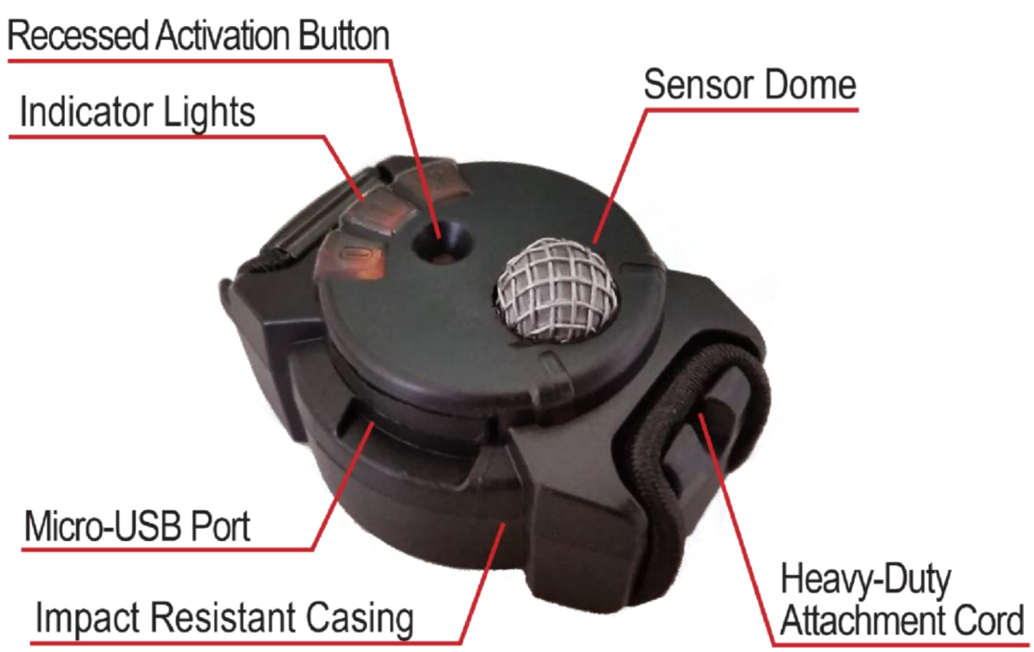

Figure 5. Black Box Blast Gauge

The pressure sensor was configured as follows:

- Oriented with the Sensor Dome facing the burst charge.
- Charge Height = 4ft Above Ground Level (AGL)
- Gauge 1 / Gauge 4 = 1ft from where article was detonated and 4 ft AGL.
- Gauge 2 / Gauge 5 = 2ft from where article was detonated and 4 ft AGL.
- Gauge 3 / Gauge 6 = 3ft from where article was detonated and 4 ft AGL.

During testing each article was detonated and the peak overpressure was measured by three gauges at various distances and angles from the detonation. Gauges 1 and 4 were placed one foot from the detonation, Gauges 2 and 5 were placed two feet from the detonation, and Gauges 3 and 6 were placed three feet from the detonation. There were a total of two identical test sites (at the Testing Range in Pawnee, Oklahoma) where the items were detonated. Figure 6 below shows the configuration and placement of the gauges at each test site.

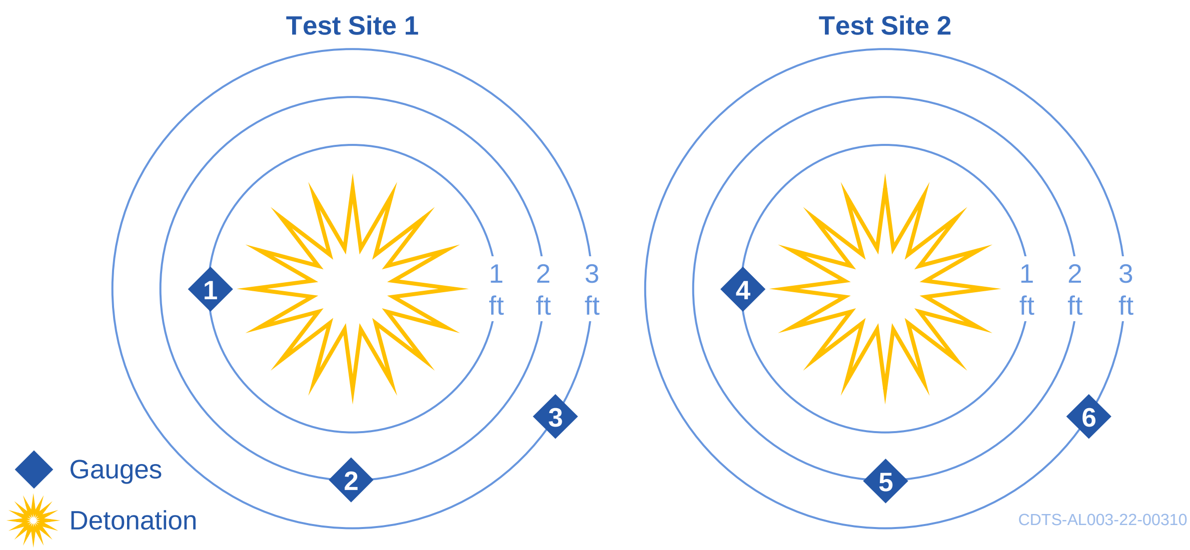

Figure 6. Configuration of Test Site

Gauges 1, 2, and 3 were placed at the first test site and Gauges 4, 5, & 6 were placed at the second test site. During testing, Gauge 1 malfunctioned and had to be replaced (with 1B). The test articles were detonated at a height of four feet from the ground. The shells were suspended from a string, and the string was run to the ground to keep the shells stationary prior to initiation. The gauges were also placed at a height of four feet from the ground, affixed to stationary stands. A GoPro camera was positioned on a tripod at a distance of six feet from the detonation and four feet off the ground.

14.2 SENSITIVITY TESTING

During this test the lift charge was initiated close to the test article (pyro device) while the movement of the device was restrained. Since the construction of consumer pyrotechnics differs from that of theatrical and display pyrotechnics, this test is designed to measure the potential for initiation of compositions containing FGMP via propagation, in a less robust configuration (consumer configuration and packaging). This test helps determine if the custom devices, containing FGMP in the burst charges, are more sensitive and subject to sympathetic explosion/detonation from initiation of the lift charge in close proximity to the restrained device. This has importance for packaging and in shipping considerations.

14.2.1 Scope

The sensitivity test assesses the sensitivity of a burst charge when a lift charge has been initiated next to the burst charge. This helps to determine if the inclusion of the FGMP in the burst charge makes it any more susceptible to sympathetic initiation.

14.2.2 Procedure

Initiation of the lift charge in close proximity to the burst charge with movement of the device restrained, as shown in Figure 7. Since the construction of consumer pyrotechnics differs from that of theatrical and display pyrotechnics, this is to measure the potential for initiation of compositions containing FGMP via propagation. The configuration of a consumer device (shell/cannister construction) is less robust than in commercial display devices. This was a pass/fail test, determining if any of the custom devices functioned/exploded as a result of sensitivity to the lift charge initiation.

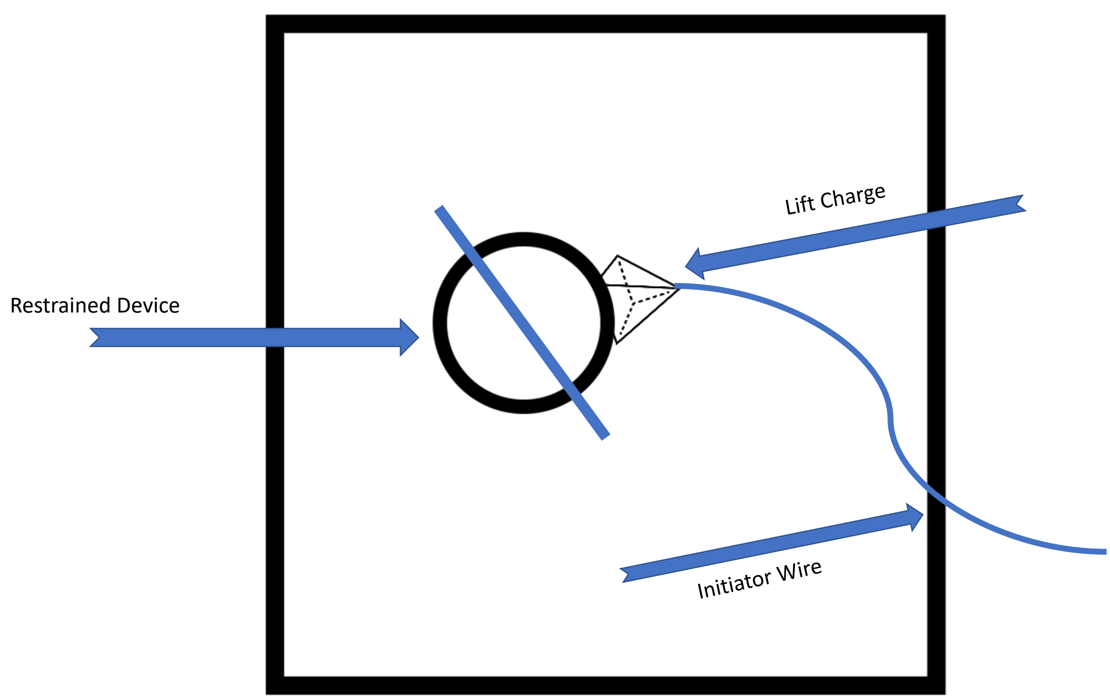

Figure 7. Sensitivity Test Layout

14.3 IMPACT TESTING

Initiation of the lift charge, with the pyrotechnic directed into a hard surface. This is to determine the susceptibility of the burst charge to initiation via impact. Again, testing will help determine if the custom devices with the FGMP in the burst charge are more susceptible to initiation from impact than the existing consumer devices.

14.3.1 Scope

This test assesses the effects of a custom device containing FGMP in the burst charge being launched into a non-moving surface.

14.3.2 Procedure

Initiation of the lift charge, with the pyrotechnic directed into a hard surface, as shown in Figure 8. This is to measure the susceptibility of the burst charge to initiation via impact. This test is a pass/fail test, determining if any of the custom devices with the FGMP in the burst charges function/explode as a result of the impact with the hard surface.

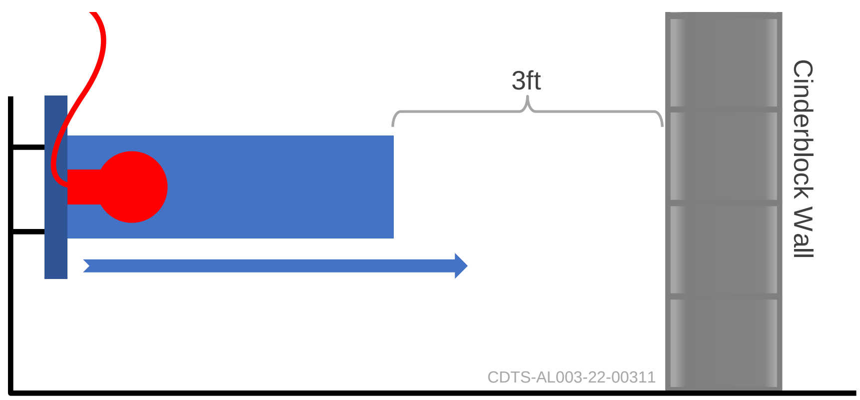

Figure 8. Impact Test Layout

15.0 Test Results

15.1 BLAST EFFECTS TESTING

Table 4 thru Table 14 displays the blast overpressure data collected during testing for the commercially available pyrotechnic articles and Table 15 thru Table 18 displays the blast effects data collected during testing for custom articles procured from Pyrotechnique by Grucci, Inc. Note that the data is not shown in order of execution but has been sorted to show items of like composition (same makeup) together. It should also be noted that several of the commercial products were not included in blast effects testing. They are C2P4, C2P5, C3P1, C3P4, C4P3, and C4P4. The items not tested were cylindrical/cannister product containers that were considerably thicker than shell-shaped products. C2P3 was also a cylindrical/cannister product but was tested prior to the consensus to delete cylindrical/cannister product containers from testing.

Table 4. Commercially Available Product from Company 1 – Product 1 (C1P1)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	37.31096	16.20797	8.04959
	42.82239	19.76139	8.37593
Standard Deviation	3.89717	2.51265	0.23075
Average	40.06668	17.98468	8.21276

(grey)	Data collected at Test Site 1 using gauges 1, 2, & 3
(light blue)	Data collected at Test Site 2 using gauges 4, 5, & 6

Table 5. Commercially Available Product from Company 1 – Product 2 (C1P2)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	13.77859	4.82250	3.91602
	11.56676	3.69846	3.04579
Standard Deviation	1.56400	0.79482	0.61534
Average	12.67267	4.26048	3.48091

(grey)	Data collected at Test Site 1 using gauges 1, 2, & 3
(light blue)	Data collected at Test Site 2 using gauges 4, 5, & 6

Table 6. Commercially Available Product from Company 1 – Product 3 (C1P3)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	12.83584	6.49044	3.95228
	15.55530	7.72326	3.95228
Standard Deviation	1.92295	0.87174	0.00000
Average	14.19557	7.10685	3.95228

(grey)	Data collected at Test Site 1 using gauges 1, 2, & 3
(light blue)	Data collected at Test Site 2 using gauges 4, 5, & 6

Table 7. Commercially Available Product from Company 2 – Product 1 (C2P1)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	24.54764	7.75952	4.78625
	18.92743	8.70226	4.31487
Standard Deviation	3.97409	0.66662	0.33331
Average	21.73753	8.23089	4.55056

(grey)	Data collected at Test Site 1 using gauges 1, 2, & 3
(light blue)	Data collected at Test Site 2 using gauges 4, 5, & 6

Table 8. Commercially Available Product from Company 2 – Product 2 (C2P2)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	10.66027	5.36640	3.33587
	12.03813	5.58395	3.26335
Standard Deviation	0.97429	0.15384	0.05128
Average	11.34920	5.47517	3.29961

	Data collected at Test Site 1 using gauges 1, 2, & 3
	Data collected at Test Site 2 using gauges 4, 5, & 6

Table 9. Commercially Available Product from Company 2 – Product 3 (C2P3)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	No data captured	18.09346	10.73279
	58.30517	20.88544	9.06486
Standard Deviation	N/A	1.97423	1.17941
Average	58.30517	19.48945	9.89883

	Data collected at Test Site 1 using gauges 1, 2, & 3
	Data collected at Test Site 2 using gauges 4, 5, & 6

Table 10. Commercially Available Product from Company 3 – Product 2 (C3P2)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	17.91216*	5.40266	3.91602
	15.44652	9.86257	4.96754
Standard Deviation	1.74347	3.15363	0.74354
Average	16.67934	7.63261	4.44178

	Data collected at Test Site 1 using gauges 1, 2, & 3	* Data was measured using replacement gauge. Red text indicates data came from second test site with gauges 4, 5, & 6.
	Data collected at Test Site 2 using gauges 4, 5, & 6	

Table 11. Commercially Available Product from Company 3 – Product 3 (C3P3)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	12.32821*	4.85876	1.34160
	17.00567	10.22516	5.11258
Standard Deviation	3.30747	3.79462	2.66649
Average	14.66694	7.54196	3.22709

	Data collected at Test Site 1 using gauges 1, 2, & 3	* Data was measured using replacement gauge. Red text indicates data came from second test site with gauges 4, 5, & 6.
	Data collected at Test Site 2 using gauges 4, 5, & 6	

Table 12. Commercially Available Product from Company 3 – Product 5 (C3P5)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	7.90456*	No data captured	2.28434
	3.00953	3.33587	No data captured
Standard Deviation	3.46130	N/A	N/A
Average	5.45704	3.33587	2.28434

	Data collected at Test Site 1 using gauges 1, 2, & 3	* Data was measured using replacement gauge. Red text indicates data came from second test site with gauges 4, 5, & 6.
	Data collected at Test Site 2 using gauges 4, 5, & 6	

Table 13. Commercially Available Product from Company 4 – Product 1 (C4P1)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	11.42172*	4.56869	2.97327
	14.28622	8.30341	3.69846
Standard Deviation	2.02550	2.64085	0.51279
Average	12.85397	6.43605	3.33587

	Data collected at Test Site 1 using gauges 1, 2, & 3	* Data was measured using replacement gauge. Red text indicates data came from second test site with gauges 4, 5, & 6.
	Data collected at Test Site 2 using gauges 4, 5, & 6	

Table 14. Commercially Available Product from Company 4 – Product 2 (C4P2)

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	14.32248*	5.11258	3.91602
	7.72326	7.75952	3.15457
Standard Deviation	4.66635	1.87167	0.53843
Average	11.02287	6.43605	3.53529

	Data collected at Test Site 1 using gauges 1, 2, & 3	* Data was measured using replacement gauge. Red text indicates data came from second test site with gauges 4, 5, & 6.
	Data collected at Test Site 2 using gauges 4, 5, & 6	

Table 15. Grucci Custom 12%

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	8.26715	4.71373	2.90075
	9.89883	4.31487	3.04579
	9.75379	4.71373	3.29961
	8.55723	5.98281	2.90075
	10.47898*	4.49617	3.15457
	10.76905	5.83777	3.00953
Standard Deviation	1.01129	0.71475	0.15455
Average	9.62084	5.00985	3.05184

	Data collected at Test Site 1 using gauges 1, 2, & 3	* Data was measured using replacement gauge. Red text indicates data came from second test site with gauges 4, 5, & 6.
	Data collected at Test Site 2 using gauges 4, 5, & 6	

Table 16. Grucci Custom 9%

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	5.40266	4.82250	3.08205
	8.15837	5.14884	No data captured
	7.21563	4.09732	No data captured
	5.54769	4.49617	2.57442
	10.22516*	4.13358	2.97327
	6.34540	4.53243	No data captured
Standard Deviation	1.83007	0.40339	0.26727
Average	7.14915	4.53847	2.87658

	Data collected at Test Site 1 using gauges 1, 2, & 3	* Data was measured using replacement gauge. Red text indicates data came from second test site with gauges 4, 5, & 6.
	Data collected at Test Site 2 using gauges 4, 5, & 6	

Table 17. Grucci Custom 6%

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	6.63548	2.97327	2.32060
	4.82250	3.22709	No data captured
	5.04006	3.84350	2.57442
	5.51143	4.13358	No data captured
Standard Deviation	0.80828	0.53649	0.17948
Average	5.50237	3.54436	2.44751

	Data collected at Test Site 1 using gauges 1, 2, & 3
	Data collected at Test Site 2 using gauges 4, 5, & 6

Table 18. Grucci Custom 3%

	Gauge 1 or 4 (1 foot) Peak Overpressure (psi)	Gauge 2 or 5 (2 feet) Peak Overpressure (psi)	Gauge 3 or 6 (3 feet) Peak Overpressure (psi)
	6.12784	No data captured	2.57442
	6.23662	2.86450	No data captured
	2.68320	3.40839	1.99427
	5.04006	3.55342	2.17557
Standard Deviation	1.65010	0.36320	0.29680
Average	5.02193	3.27544	2.24809

	Data collected at Test Site 1 using gauges 1, 2, & 3
	Data collected at Test Site 2 using gauges 4, 5, & 6

15.2 SENSITIVITY TESTING

For this study, lift charges were placed in intimate contact with commercial and custom pyrotechnic products and initiated individually. Before each test, the lift charge for each pyrotechnic shell was removed. The shells were restrained, and the lift charge was placed in direct contact with the side of the shell. The lift charge was then ignited and following the burning of the lift charge, results were observed and graded as either Pass or Fail. If the lift charge ignited the product a grade of Fail was assigned if the lift charge did not ignite the product a grade of Pass was assigned. Each commercial item was tested three times and the results are displayed in Table 19. It should also be noted that several of the commercial products were not included in sensitivity testing. They are C2P3, C2P4, C2P5, C3P1, C3P4, C4P3, and C4P4. The items not tested were cylindrical/cannister product containers that were considerably thicker than shell-shaped products. All researchers present during the testing agreed that these products did not need to undergo the sensitivity test, as the lift charge would not be able to breach the thick container wall.

Table 19. Sensitivity Testing Results for Commercially Available Pyrotechnic Products

	Grade (1st test)	Grade (2nd test)	Grade (3rd test)
Commercially Available Product from Company 1 – Product 1 (C1P1)	These items were tested, but not included in the results due to technical difficulties with the camera recording video footage of each test.		
Commercially Available Product from Company 1 – Product 2 (C1P2)			
Commercially Available Product from Company 1 – Product 3 (C1P3)			
Commercially Available Product from Company 2 – Product 1 (C2P1)	Pass	Pass	Pass
Commercially Available Product from Company 2 – Product 2 (C2P2)	Pass	Pass	Pass
Commercially Available Product from Company 3 – Product 2 (C3P2)	Pass	Pass	Pass
Commercially Available Product from Company 3 – Product 3 (C3P3)	Pass	Pass	Pass
Commercially Available Product from Company 3 – Product 5 (C3P5)	Pass	Pass	Pass
Commercially Available Product from Company 4 – Product 1 (C4P1)	Pass	Pass	Pass
Commercially Available Product from Company 4 – Product 2 (C4P2)	Pass	Pass	Pass

For the custom shells procured from Pyrotechnique by Grucci, Inc. shells 41-120 were used for sensitivity testing. A total of 80 tests of the custom shells were conducted. The same grading used for the commercially available pyrotechnic products was used to grade the custom shells. The results of the custom articles are shown in Table 20, all tests of the custom shells produced the same result

Table 20. Sensitivity Testing Results for Custom Shells

	Grade
Grucci Custom 12% (Shells 41-64, total of 24 tests)	Pass
Grucci Custom 9% (Shells 65-88, total of 24 tests)	Pass
Grucci Custom 6% (Shells 89-104, total of 16 tests)	Pass
Grucci Custom 3% (Shells 105-120, total of 16 tests)	Pass

15.3 IMPACT TESTING

For this test the products were ignited in a mortar tube that was positioned and directed towards a cinderblock wall three feet away from the end of the tube and the results were observed and graded as either Go or No Go. If the product immediately exploded upon impact a grade of Go was assigned. If the product had a delayed explosion upon impact or none at all a grade of No Go was assigned. The results of the impact testing are shown in Table 21.

Table 21. Impact Testing Results for Commercially Available Pyrotechnic Products

	Grade (1st test)	Grade (2nd test)	Grade (3rd test)
Commercially Available Product from Company 1 – Product 1 (C1P1)	These items were tested, but not included in the results due to technical difficulties with the camera recording video footage of each test.		
Commercially Available Product from Company 1 – Product 2 (C1P2)			
Commercially Available Product from Company 1 – Product 3 (C1P3)			
Commercially Available Product from Company 2 – Product 1 (C2P1)	No Go	No Go	Go
Commercially Available Product from Company 2 – Product 2 (C2P2)	No Go	Go	Go
Commercially Available Product from Company 2 – Product 3 (C2P3)	No Go	No Go	Go
Commercially Available Product from Company 2 – Product 4 (C2P4)	Go	Go	No Go
Commercially Available Product from Company 2 – Product 5 (C2P5)	Go	Go	No Go
Commercially Available Product from Company 3 – Product 1 (C3P1)	Go	No Go	Go
Commercially Available Product from Company 3 – Product 2 (C3P2)	Go	Go	Go
Commercially Available Product from Company 3 – Product 3 (C3P3)	No Go	Go	Go
Commercially Available Product from Company 3 – Product 4 (C3P4)	No Go	No Go	Go
Commercially Available Product from Company 3 – Product 5 (C3P5)	No Go	No Go	No Go
Commercially Available Product from Company 4 – Product 1 (C4P1)	No Go	No Go	No Go
Commercially Available Product from Company 4 – Product 2 (C4P2)	No Go	No Go	No Go
Commercially Available Product from Company 4 – Product 3 (C4P3)	No Go	No Go	No Go
Commercially Available Product from Company 4 – Product 4 (C4P4)	Go	Go	Go

For the custom shells procured from Pyrotechnique by Grucci, Inc. shells 131-190 were used for impact testing. A total of 60 tests of the custom shells were conducted. The same grading used for the commercially available pyrotechnic products was used to grade the custom shells. The results of the custom shells are shown in Table 22, all tests of the custom shells produced the same result. Shells 152, 159, 176, and 181 did not immediately ignite upon impact with the hard surface/wall, but very shortly afterwards.

Table 22. Impact Testing Results for Custom Shells

	Grade
Grucci Custom 12% (Shells 131-144, total of 14 tests)	Pass
Grucci Custom 9% (Shells 145-168, total of 24 tests)	Pass
Grucci Custom 6% (Shells 169-184, total of 16 tests)	Pass
Grucci Custom 3% (Shells 185-190, total of 6 tests)	Pass

PART V: PHASE 4 – FINAL REPORTING

16.0 Findings

After review and analysis of the test data of FGMP in pyrotechnic compositions (specifically in burst charges), the APT Research Subject Matter Experts (SME) conclusions are that the test results did not indicate the presence of additional hazards effecting classification. These conclusions are based on the comparisons made between the specific commercially available (consumer) pyrotechnic devices selected and the custom devices made specifically for this study. In general, for the blast effects testing, the Grucci custom products did not produce higher peak overpressure numbers than the commercially available pyrotechnic products. In general, for the sensitivity and impact testing the Grucci custom products did not explode more frequently than the commercially available pyrotechnic products upon impact. Detailed observations of the results are documented in the report provided by OSU, included as Appendix A. Review of the test results (OSU test report) suggest that these items, as constructed for this study, are not more hazardous than other commercially available HD 1.4 pyrotechnic products already on the market. However as noted, these results may vary and a different conclusion may result depending on specific shell configurations, concentrations of FGMP in burst charges (% of total burst charge weight), or differences in the chemical composition of the burst charges that another manufacturer may employ.

17.0 Recommendations

This project provides initial findings for determining the feasibility of safely including FGMP in the burst charges of HD 1.4 pyrotechnic devices. The testing completed in Phase 3 did not provide sufficient evidence to modify the regulations but did provide enough evidence to warrant more refined and comprehensive testing. The following recommendations are focused on additional testing which once completed and if the testing is favorable would justify revisions to the current regulations or standards. A thorough design of experiments and objectives should be conducted prior to additional testing, a few suggestions are listed below.

1. Determine if other factors (e.g. different chemical compositions of burst charges, overall net explosive weight of the device, different shell constructions, etc.) impact safety when including FGMP in the burst charges of HD 1.4 devices. While the goal of this study was to compare the relative safety of existing HD 1.4 devices to custom devices containing varying percentages of FGMP in the burst charges, additional testing should examine the sensitivity and relative energy of actual FGMP compositions as compared to commercially available pyrotechnic products.

2. Due to proprietary aspects, specific details of the commercially available pyrotechnic (HD 1.4) products was not available, only that these products met current regulations. The chemical compositions of the custom devices was well defined. Additional testing of the chemical compositions of both commercially available pyrotechnic (HD 1.4) products and FGMP devices from the same source would provide a more accurate "apples to apples" comparisons of the relative sensitivity of the mixtures and would provide additional data to be considered along with the results of the three tests that were performed as part of this study. Proprietary knowledge of commercially available pyrotechnic (HD 1.4) products may be able to be achieved through the execution of non-disclosure agreements.
3. UN classification tests to include impact sensitivity, friction sensitivity, small scale fire, thermal stability, and package tests could be within the scope of additional testing.
4. For performance testing like that done by OSU, the use of high speed cameras during testing would also allow for minor reactions to be noted that may otherwise be missed.
5. Additional testing of higher percentages (>12%) of FGMP would assist in identifying if there is a specific percentage of FGMP at which additional hazards are of concern.

18.0 Adopted Suggestions

The FGMP findings did not provide sufficient justification for adopting any revisions to current regulation or standards. However, the findings do provide justification that adopting revisions to the current regulations or standards could be recommended once comprehensive testing provides additional favorable data.

Appendix A – Oklahoma State Report

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FORENSIC SCIENCES

Research Project Report

Oklahoma State University – Center for Health Sciences
School of Forensic Sciences

Date:	08/25/2022
Project:	DOT PHMSA Fine Grain Metal Powder Standards for Consumer Pyrotechnics
Project Owner:	A-P-T Research, Inc. 4950 Research Dr. Huntsville, AL 35805 Phone: 256.327.3389 www.apt-research.com

Executive Summary:

As outlined in the test plan provided by A-P-T, Oklahoma State University performed blast effects, sensitivity, and impact tests at their Explosives Research and Testing Range in Pawnee, OK. For each test discussed below, current commercial pyrotechnic products were compared to proposed or custom products with burst charges containing fine grain metal powder (FGMP).

For the blast effects testing, 42 products from various manufacturers, were initiated individually. Following each initiation, blast overpressure gauge data was collected, and a video camera captured visual representation of each test. The three pressure gauges were leveled at a shot height of 4 feet, and placed 1, 2, and 3 feet from each test. For commercial pyrotechnics, the cylindrical or cannister pyrotechnic products produced greater pressure than shell-shaped products. For the custom products containing varying percentages of FGMP (3, 6, 9, and 12%), the blast pressures observed were lower on average compared to commercial products. Testing of the custom products also demonstrated a direct relationship between FGMP percentage and blast pressure.

For the sensitivity testing, individual lift charges were placed in intimate contact with a restrained pyrotechnic product and the lift charge was initiated. The testing results were evaluated on a binary response, either the energy from the lift charge ignited or did not ignite the restrained product through the product container/casing. For all sensitivity tests, the lift charges did not initiate the restrained device.

For the impact testing, complete pyrotechnic products were initiated toward a hard surface 3 feet away, resulting in an impact event. The testing results were evaluated on a binary response, either the pyrotechnic product ignited or did not ignite upon impact with the hard surface. Commercial products demonstrated variable results with regards

to impact sensitivity based on the test setup. All custom products did not ignite upon impact, but several ignited shortly following the impact stimulus.

Based on the results of this study, the use of FGMP in the custom products did not demonstrate increased blast pressure, sensitivity, and impact results compared to commercial pyrotechnic products. An important note is that these results only pertain to the custom products provided to the researchers. Any addition to the pyrotechnic content of these products or use of FGMP in the burst charge of another product will need to be evaluated.

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Pyrotechnic Products:

All three tests in this study utilized commercial and custom pyrotechnic products for comparison purposes. The pyrotechnic composition of the commercial products was not provided by the manufacturers. Chemical characterization of these products was not part of this research, nor did the manufacturers want the composition of their products tested. However, researchers were provided with some previous testing information that evaluated pyrotechnic composition. The custom products were specifically created for this study and contained a certain percentage of fine grain metal powder (FGMP) in the burst charge. This composition information was provided by the manufacturer of the custom products.

The commercial products tested in this study were obtained from five different companies, and each company had several different products. These products were either cylindrical- or shell-shaped. Figure 1, below, demonstrates the difference between the cylindrical (left) and shell (right) shapes of commercial pyrotechnic products.

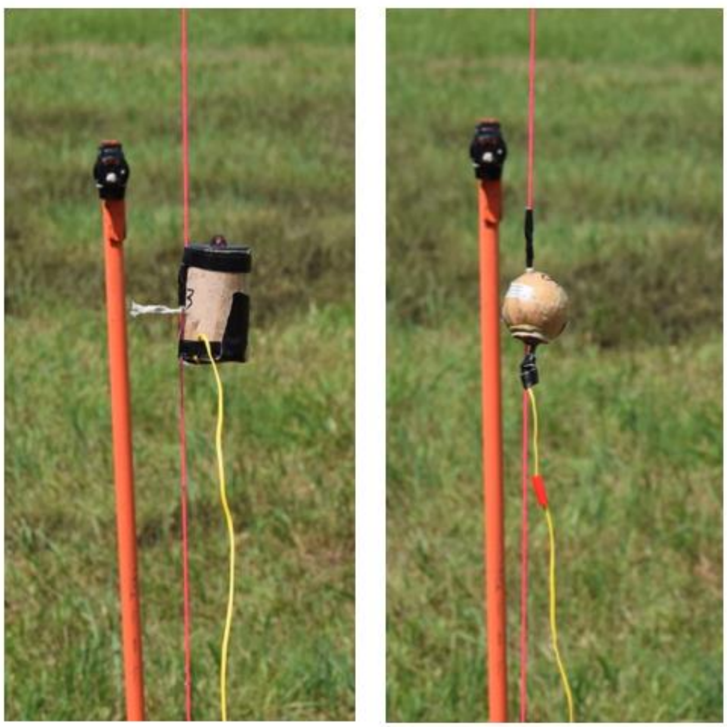

Figure 1. Examples of Cylindrical and Shell Products. Left, is an example of products tested that had a cylindrical shape. Right, is an example of products that had a shell shape. Imaging not to scale.

The custom products tested in this study were obtained from one company. All custom products provided were shell-shaped. Therefore, the researchers decided that any comparisons addressed in this study were limited to shell-shaped pyrotechnics. 200 custom products were provided and labeled by the manufacturer as 1-200. The first 40 products were created for blast effects testing, 41-120 for sensitivity testing, and 121-

200 for impact testing. Within each group of custom products for the tests, there was variable percentages of FGMP within the burst charge of each product. Levels of FGMP percentage included 12, 9, 6, and 3%. Products 1-12, 41-64, and 121-144 had a burst charge with 12% FGMP. Products 13-24, 65-88, and 145-168 had a burst charge with 9% FGMP. Products 25-32, 89-104, and 169-184 had a burst charge with 6% FGMP. Products 33-40, 105-120, and 185-200 had a burst charge of 3% FGMP.

Table 1, below, contains pyrotechnic content information of commercial and custom products. The commercial product information was provided to researchers from another research study. The custom product information was provided by the manufacturer. To retain anonymity, the commercial products are labeled as product A, B, and C, and the pyrotechnic content of 5 shells each are listed. Additionally, the pyrotechnic content of the provided custom products is listed at the bottom of the table. All custom products were reported by the manufacturer to have the same overall pyrotechnic weight of 18.2 grams. The only difference in composition of the custom products was the FGMP percentage in the burst charge, discussed above.

Table 1. Pyrotechnic Content Comparisons. Pyrotechnic composition information for three commercial products, 5 shells each, were provided by another research project. Products are listed as A, B, and C, with the number detonating an example shell (1-5). Break charge in grams and break charge as a fraction compared to overall weight was provided. Pyrotechnic weight was calculated, and average and standard deviations determined for each of the three commercial products. Custom products listed at the bottom all contain the same amount of burst charge and pyrotechnic weight.

Pyrotechnic Content Comparisons					
Example Product	**Burst Charge (grams)**	**Burst Charge (fraction)**	**Pyrotechnic Weight**	**Average Weight**	**Standard Deviation**
Commercial A1	4.0	0.16	25.0		
Commercial A2	4.3	0.17	25.3		
Commercial A3	3.8	0.16	23.8		
Commercial A4	3.4	0.13	26.2		
Commercial A5	4.5	0.17	26.5	**25.3**	**1.1**
Commercial B1	3.5	0.12	29.2		
Commercial B2	3.6	0.12	30.0		
Commercial B3	3.4	0.11	30.9		
Commercial B4	3.3	0.10	33.0		
Commercial B5	3.7	0.12	30.8	**30.8**	**1.4**
Commercial C1	5.0	0.21	23.8		
Commercial C2	4.2	0.17	24.7		
Commercial C3	3.7	0.16	23.1		
Commercial C4	5.5	0.23	23.9		
Commercial C5	4.8	0.20	24.0	**23.9**	**0.6**
Custom Products	3.2	0.18	**18.2**		

Blast Effects Testing:

Methodology

For this study, blast overpressures were collected from 42 pyrotechnic products, consisting of commercial (22 tests) and custom products (20 tests). Before a test, the lift charge from the product was removed. Each product was then suspended 4 feet from the ground. For the collection of blast pressure data, three Blast Gauge System pressure gauges were placed at a height of 4 feet, and at a distance of 1, 2, and 3 feet from each test. A camera was used to capture video footage of each test. The height of the camera tripod was 4 feet and was placed 6 feet away from each test. Figure 2, below, was the testing setup for the study, with graphics denoting pressure gauge distances from each test.

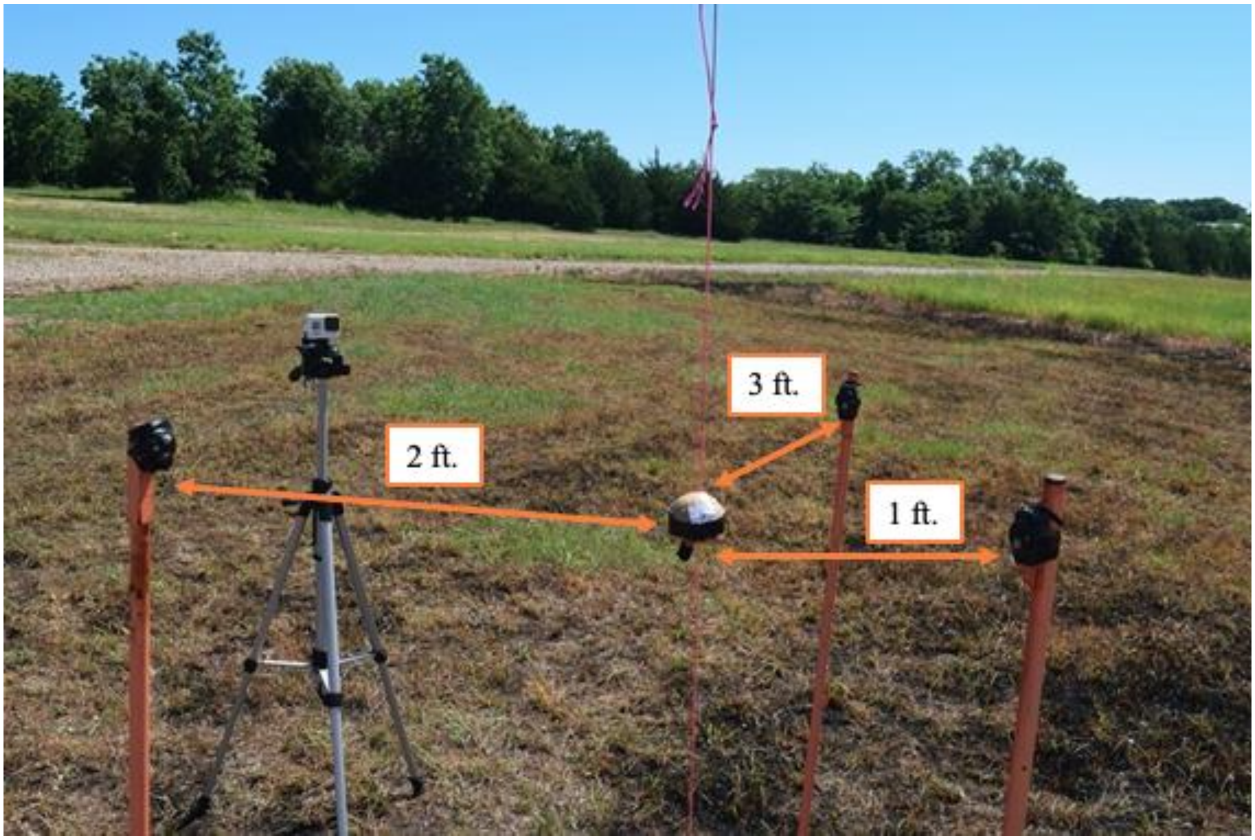

Figure 2. Setup of Blast Pressure Testing. Product suspended from a height of 4 feet. Blast pressure gauges and GoPro camera placed at the same height of 4 feet. As depicted with the arrows and labels, a gauge was placed 1, 2, and 3 feet away from each test.

Commercial products were labeled with company number designated as "C#" followed by product number designated as "P#." Products tested in this study included: C1P1, C1P2, C1P3, C2P1, C2P2, C2P3, C3P5, C4P1, C4P2. Identifying information about each commercial product were documented, but not included in this report to provide anonymity. All commercial products were shells, except for C1P1 and C2P3 which were cylindrical in shape.

Custom products were specifically designed by manufacturers for this research, and contained varying amounts of FGMP percentage. Custom products tested in this study were labeled in numerical order by manufacturer and included: 1, 2, 3, 4, 5, 6, 13, 14, 15, 16, 17, 18, 25, 26, 27, 28, 33, 34, 35, and 36. Products 1-6 contained 12% FGMP, 13-18 contained 9% FGMP, 25-28 contained 6% FGMP, and 33-36 contained 3% FGMP.

As an example, Figure 3, below, is an image of one of the products ignited during the blast effects testing.

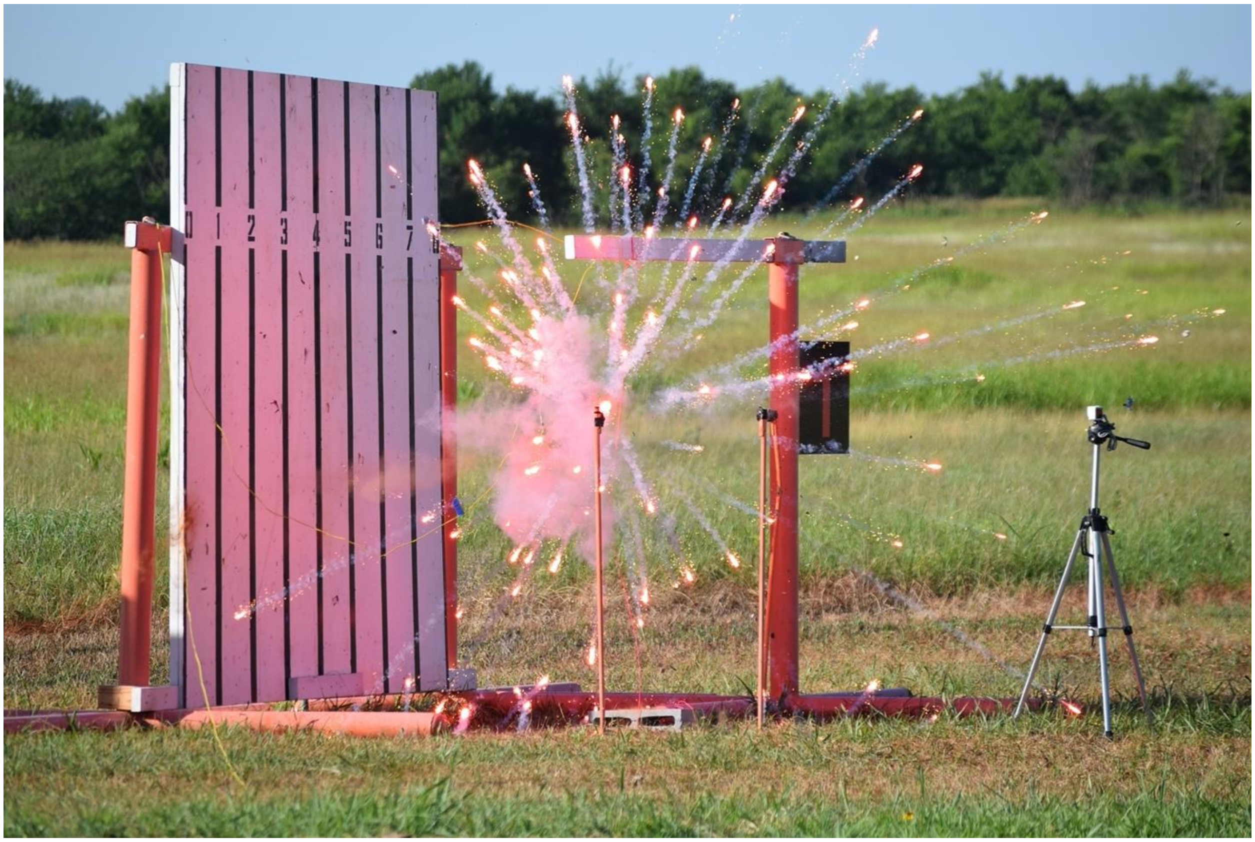

Figure 3. Ignition of Pyrotechnic Shell During Blast Effects Testing.

Results

Pressure data is organized below in Tables 2-4, which represent blast pressure gauges from 1, 2, and 3 feet, respectively. All values listed have units of pounds per square inch (psi). Any value listed as "ND" represented a result that was not detected by the pressure gauge. For Table 2, the single ND result for C2P3 was a result of the blast pressure overloading the gauge. For Tables 3 and 4, all ND results were a result of the blast gauge not receiving a sufficient pressure to register a signal. Any value left blank in the following tables denotes that the products were not tested or repeated further.

Table 2. Blast Pressure Data from 1 ft. Distance. Products tested are listed in first column, followed by how many replicates were tested. Averages and standards deviations were calculated were applicable. All values below are listed in pounds per square inch (psi).

Blast Gauge Distance					1 ft.			
Product	**1**	**2**	**3**	**4**	**5**	**6**	**Average**	**Standard Deviation**
1-6	8.27	9.90	9.75	8.56	10.48	10.77	9.62	1.01
13-18	5.40	9.90	7.22	5.55	10.23	6.35	7.44	2.13
25-28	6.64	4.82	5.04	5.51			5.50	0.81
33-36	6.13	6.24	2.68	5.04			5.02	1.65
C1P1	37.31	42.82					40.07	3.90
C1P2	13.78	11.57					12.67	1.56
C1P3	12.84	15.56					14.20	1.92
C2P1	24.55	18.93					21.74	3.97
C2P2	10.66	12.04					11.35	0.97
C2P3	ND	58.31					58.31	N/A
C3P2	17.91	15.45					16.68	1.74
C3P3	12.33	17.01					14.67	3.31
C3P5	7.90	3.01					5.46	3.46
C4P1	11.42	14.29					12.85	2.03
C4P2	14.32	7.72					11.02	4.67

Table 3. Blast Pressure Data from 2 ft. Distance. Products tested are listed in first column, followed by how many replicates were tested. Averages and standards deviations were calculated were applicable. All values below are listed in pounds per square inch (psi).

Blast Gauge Distance					2 ft.			
Product	**1**	**2**	**3**	**4**	**5**	**6**	**Average**	**Standard Deviation**
1-6	4.71	4.31	4.71	8.56	4.50	10.77	6.26	2.73
13-18	4.82	5.15	4.10	4.50	4.13	4.53	4.54	0.40
25-28	2.97	3.23	3.84	4.13			3.54	0.54
33-36	ND	2.86	3.41	3.55			3.28	0.36
C1P1	16.21	19.76					17.99	2.51
C1P2	4.82	3.70					4.26	0.79
C1P3	6.49	7.72					7.11	0.87

C2P1	7.76	8.70					8.23	0.66
C2P2	5.37	5.58					5.48	0.15
C2P3	18.09	20.89					58.31	1.98
C3P2	5.4	9.86					7.63	3.15
C3P3	4.86	10.23					7.55	3.80
C3P5	ND	3.34					3.34	N/A
C4P1	4.57	8.30					6.44	2.64
C4P2	5.11	7.76					6.44	1.87

Table 4. Blast Pressure Data from 3 ft. Distance. Products tested are listed in first column, followed by how many replicates were tested. Averages and standards deviations were calculated were applicable. All values below are listed in pounds per square inch (psi).

Blast Gauge Distance					3 ft.			
Product	**1**	**2**	**3**	**4**	**5**	**6**	**Average**	**Standard Deviation**
1-6	2.90	3.05	3.30	2.90	3.15	3.01	3.05	0.15
13-18	3.08	ND	ND	2.57	2.97		2.88	0.27
25-28	2.32	ND	2.57	ND			2.45	0.18
33-36	2.57	ND	1.99	2.18			2.25	0.30
C1P1	8.05	8.38					8.22	0.23
C1P2	3.92	3.05					3.49	0.62
C1P3	3.95	3.95					3.95	0.00
C2P1	4.79	4.31					4.55	0.34
C2P2	3.34	3.26					3.30	0.06
C2P3	10.73	9.06					9.90	1.18
C3P2	3.92	4.97					4.45	0.74
C3P3	1.34	5.11					3.23	2.67
C3P5	2.28	ND					2.28	N/A
C4P1	2.97	3.70					3.34	0.52
C4P2	3.92	3.15					3.54	0.54

Discussion/Conclusion

Based on the blast effects data, commercial pyrotechnic products that were cylindrical in shape produced the highest pressure results, as seen for C1P1 and C2P3. The blast gauge 1 foot away during the C2P3 test was overloaded, meaning the pressure was too great to register a result. Following this overload, cylindrical products were no longer tested to preserve integrity of each pressure gauge. The blast pressure generated from the two cylindrical products were roughly two times or more than all the other products tested. In addition, since all custom products were shell-shaped, researchers determined all comparisons would need to be made between shell-shaped commercial products. Therefore, any comparisons below will not include these results.

Comparing the results of Table 1, the commercial shell products produced an average of 13.40 psi compared to 7.22 psi for the custom shell products. The highest FGMP percentage products (1-6) produced an average of 9.62 psi, which is lower than the average of commercial shell products tested. Additionally, Products 1-6 demonstrated a lower average blast pressure than every commercial shell product, except for C3P5.

Based on information listed in the “Pyrotechnic Products” section, each custom product contained an approximate pyrotechnic weight of 18.2 grams. Researchers are uncertain whether this amount would be the extent of pyrotechnic composition within the shells if produced for commercial use. If 18.2 grams is the extent, the results from this research demonstrated that the custom products provided with a burst charge containing FGMP at 12% or lower did not have higher blast pressures compared to the other commercial products. If any pyrotechnic composition would be added to the custom products provided, additional testing would be needed to confirm and compare blast pressures. Similarly, any new custom or proposed products in the future that contain burst charges with FGMP would also need to be tested.

After review of the custom products alone, results demonstrated a direct relationship between blast pressure and FGMP percentage. The highest FGMP percentage was 12% in Shots 1-6. For every gauge (Tables 1-3), the average pressure was the highest for the Shots 1-6 group among the custom products . This trend continues for the remaining FGMP percentage groups of 9, 6, and 3% for all three pressure gauges, positioned at 1, 2, and 3 feet away from each test.

Sensitivity Testing:

Methodology

For this study, lift charges were placed in intimate contact with commercial and custom pyrotechnic products and initiated individually. All products tested were pyrotechnic shells. Pyrotechnic cylinders were not tested. Before each test, the lift charge for each pyrotechnic shell was removed and the burst charge fuse was covered with tape. The shells were restrained and the lift charge was placed in direct contact with the side of the shell. The lift charge was then ignited and following the burning of the lift charge, results were observed. Either the lift charge ignited or did not ignite the product through the product casing/container. Figure 4, below, is an example of how each product was set up prior to testing.

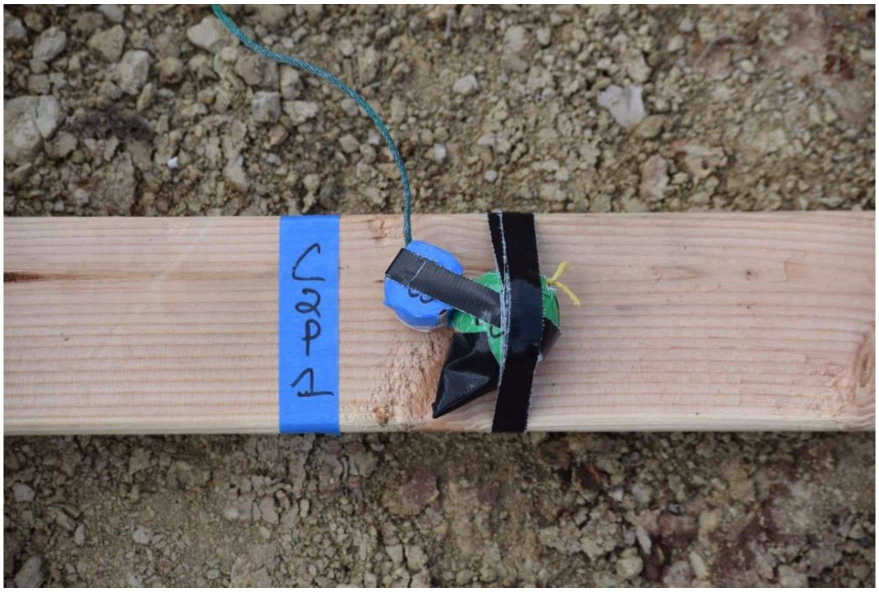

Figure 4. Sensitivity Test Setup. Commercial and custom pyrotechnic shells were set up in this manner. Each shell (green item in this example) was restrained, and the lift charge (blue item in this example) was placed in direct contact with the side of the shell.

Commercial products were labeled with company number designated as “C#” followed by product number designated as “P#.” Products tested in this study included: C2P1, C2P2, C4P1, C4P2, C3P2, C3P3, and C3P5. Company 1 Products 1-3 were also tested, but not included in the results due to technical difficulties with the camera recording video footage of each test. Any commercial products that were cylindrical in shape were not tested in this study. Visual examination of these products demonstrated that the cardboard container/casing was considerably thicker than the shell-shaped products. As a result, researchers agreed that the cylindrical products did not need to be tested since the lift charge would not be able to breach the thick container/casing. Custom products tested in this study were labeled in numerical order by manufacturer and included: 41-120.

Results

None of the commercial and custom products initiated due to the lift charge igniting the pyrotechnic shell through the container. For the commercial products, 1 out of 21 tests resulted in a delayed ignition of the pyrotechnic shell, or 4.8% of the tests. For the custom products, 39 out of 80 tests resulted in a delayed ignition of the pyrotechnic shell, or 48.8% of the tests.

Discussion/Conclusion

When the lift charge was removed prior to testing, the exposed burst charge fuse was covered so that the heat/flame/spark from the lift charge fuse and/or the lift charge would not ignite the product as designed. However, many of the tests resulted with igniting of the product, but all ignitions were delayed. After discussion and review of the videos captured during the testing, it was concluded that the lift charge did not ignite the shell through the container, but rather via the burst charge fuse.

Two possible explanations for the lift charge igniting the burst charge fuse are 1) the burst charge fuse was not protected sufficiently and 2) the lift charge quantity overwhelmed the burst charge fuse protection. Four random lift charges were selected, two from the commercial products and two from the custom products. The two lift charges from the commercial products weighed 3.63 and 3.60 grams, while the two from the custom products weighed 11.92 and 11.86 grams. This discrepancy between the lift charge quantity may explain why the custom products resulted in many more delayed ignitions compared to the commercial products.

Overall, the results from this study demonstrated that the custom products provided, which contained FGMP at small percentages, did not result in increased sensitivity, based on the parameters of this specific test plan, compared to other commercial products.

Impact Testing:

Methodology

For this study, complete commercial and custom pyrotechnic products were initiated in a mortar tube that was positioned and directed towards a cinderblock wall 3 feet away from the end of the tube. Results of this test were to determine if this impact stimulus would ignite the pyrotechnic products. Figure 5, below, is an example of the test setup.

Figure 5. Impact Sensitivity Test Setup. Mortar tubes were lined up facing a cinderblock wall (3 feet away). Commercial and custom pyrotechnic products were loaded and ignited, resulting in each product striking the wall.

Commercial products were labeled with company number designated as “C#” followed by product number designated as “P#.” Products tested in this study in triplicate included: C2P1, C2P2, C2P3, C2P4, C2P5, C3P1, C3P2, C3P3, C3P4, C3P5, C4P1, C4P2, C4P2, C4P3, and C4P4. Company 1 Products 1-3 were also tested, but not included in the results due to technical difficulties with the camera recording video footage of each test. Custom products tested in this study were labeled in numerical order by manufacturer and included: 121-200.

As an example, Figure 6, below, is an image of one of the products that ignited following impact with the hard surface/wall.

Figure 6. Ignition of Pyrotechnic Shell due to Impact.

Results

The following table includes the Impact Sensitivity Test data. Results are listed as either "Go" for immediate ignition of pyrotechnic product upon impact or "No Go" for delayed ignition or no ignition.

Table 5. Impact Sensitivity Data for Commercial Products. Each product tested is listed in the first column. All commercial products were tested in triplicate. "Go" indicates immediate ignition of product following impact with the hard surface/wall. "No Go" indicates delayed ignition or no ignition of product following impact with the hard surface/wall.

Commercial Products			
Product	**Result 1**	**Result 2**	**Result 3**
C2P1	No Go	No Go	Go
C2P2	No Go	Go	Go
C2P3	No Go	No Go	Go
C2P4	Go	Go	No Go
C2P5	Go	Go	No Go
C3P1	Go	No Go	Go
C3P2	Go	Go	Go
C3P3	No Go	Go	Go
C3P4	No Go	No Go	Go
C3P5	No Go	No Go	No Go
C4P1	No Go	No Go	No Go
C4P2	No Go	No Go	No Go
C4P3	No Go	No Go	No Go
C4P4	Go	Go	Go

Results for the custom products, 121-200 were all determined to be "No Go." A table was not produced due to the fact that all products tested would be labeled with the same result. There were 6 products (out of 80) that did not immediately ignite upon impact with the hard surface/wall, but very shortly afterwards. The shots that demonstrated this result were 130, 152, 159, 176, 181, and 197.

Discussion/Conclusion

After review of the results, this test as designed did not show increased impact sensitivity of custom products containing FGMP compared to commercial products. The commercial pyrotechnics produced variable results between the companies and products. Meanwhile, the custom pyrotechnics produced no results of immediate ignition upon impact with the hard surface. However, and as discussed above, if the custom products provided do not represent the extent of pyrotechnic composition within the shells, further testing would be needed to provide direct comparison to the commercial products tested. Similarly, any new custom or proposed products in the future that contain burst charges with FGMP would also need to be tested.

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Appendix B – Shell List

06/03/2022 Pyrotechnique by Grucci, Inc.

Revision 3 APT-Research Shell List

Shell Nr	FGMP %	Casings	Burst Powder		Lift Powder	Star (1), (2)	Gum Tape	Time Fuse
			Rice Powder 25.5 (4)	Crossette Flash (3)	5FA Black Powder (5)			
		(ea)	(g)	(g)	(g)	(g)	(ft)	(in)
Test 1: 40 total shells only (no attached lift charge)								
1	12%	1	2.82	0.38	0	15	15	1
2	12%	1	2.82	0.38	0	15	15	1
3	12%	1	2.82	0.38	0	15	15	1
4	12%	1	2.82	0.38	0	15	15	1
5	12%	1	2.82	0.38	0	15	15	1
6	12%	1	2.82	0.38	0	15	15	1
7	12%	1	2.82	0.38	0	15	15	1
8	12%	1	2.82	0.38	0	15	15	1
9	12%	1	2.82	0.38	0	15	15	1
10	12%	1	2.82	0.38	0	15	15	1
11	12%	1	2.82	0.38	0	15	15	1
12	12%	1	2.82	0.38	0	15	15	1
13	9%	1	2.91	0.29	0	15	15	1
14	9%	1	2.91	0.29	0	15	15	1
15	9%	1	2.91	0.29	0	15	15	1
16	9%	1	2.91	0.29	0	15	15	1
17	9%	1	2.91	0.29	0	15	15	1
18	9%	1	2.91	0.29	0	15	15	1
19	9%	1	2.91	0.29	0	15	15	1
20	9%	1	2.91	0.29	0	15	15	1
21	9%	1	2.91	0.29	0	15	15	1
22	9%	1	2.91	0.29	0	15	15	1
23	9%	1	2.91	0.29	0	15	15	1
24	9%	1	2.91	0.29	0	15	15	1
25	6%	1	3.01	0.19	0	15	15	1
26	6%	1	3.01	0.19	0	15	15	1
27	6%	1	3.01	0.19	0	15	15	1
28	6%	1	3.01	0.19	0	15	15	1
29	6%	1	3.01	0.19	0	15	15	1
30	6%	1	3.01	0.19	0	15	15	1
31	6%	1	3.01	0.19	0	15	15	1
32	6%	1	3.01	0.19	0	15	15	1

Shell Nr	FGMP %	Casings	Burst Powder		Lift Powder	Star (1), (2)	Gum Tape	Time Fuse
			Rice Powder 25.5 (4)	Crossette Flash (3)	5FA Black Powder (5)			
		(ea)	(g)	(g)	(g)	(g)	(ft)	(in)
33	3%	1	3.10	0.10	0	15	15	1
34	3%	1	3.10	0.10	0	15	15	1
35	3%	1	3.10	0.10	0	15	15	1
36	3%	1	3.10	0.10	0	15	15	1
37	3%	1	3.10	0.10	0	15	15	1
38	3%	1	3.10	0.10	0	15	15	1
39	3%	1	3.10	0.10	0	15	15	1
40	3%	1	3.10	0.10	0	15	15	1
Test 2: 80 total shells with detached lift charges								
41	12%	1	2.82	0.38	12	15	15	1
42	12%	1	2.82	0.38	12	15	15	1
43	12%	1	2.82	0.38	12	15	15	1
44	12%	1	2.82	0.38	12	15	15	1
45	12%	1	2.82	0.38	12	15	15	1
46	12%	1	2.82	0.38	12	15	15	1
47	12%	1	2.82	0.38	12	15	15	1
48	12%	1	2.82	0.38	12	15	15	1
49	12%	1	2.82	0.38	12	15	15	1
50	12%	1	2.82	0.38	12	15	15	1
51	12%	1	2.82	0.38	12	15	15	1
52	12%	1	2.82	0.38	12	15	15	1
53	12%	1	2.82	0.38	12	15	15	1
54	12%	1	2.82	0.38	12	15	15	1
55	12%	1	2.82	0.38	12	15	15	1
56	12%	1	2.82	0.38	12	15	15	1
57	12%	1	2.82	0.38	12	15	15	1
58	12%	1	2.82	0.38	12	15	15	1
59	12%	1	2.82	0.38	12	15	15	1
60	12%	1	2.82	0.38	12	15	15	1
61	12%	1	2.82	0.38	12	15	15	1
62	12%	1	2.82	0.38	12	15	15	1
63	12%	1	2.82	0.38	12	15	15	1
64	12%	1	2.82	0.38	12	15	15	1
65	9%	1	2.91	0.29	12	15	15	1
66	9%	1	2.91	0.29	12	15	15	1
67	9%	1	2.91	0.29	12	15	15	1
68	9%	1	2.91	0.29	12	15	15	1
69	9%	1	2.91	0.29	12	15	15	1

Shell Nr	FGMP %	Casings	Burst Powder		Lift Powder	Star (1), (2)	Gum Tape	Time Fuse
			Rice Powder 25.5 (4)	Crossette Flash (3)	5FA Black Powder (5)			
		(ea)	(g)	(g)	(g)	(g)	(ft)	(in)
70	9%	1	2.91	0.29	12	15	15	1
71	9%	1	2.91	0.29	12	15	15	1
72	9%	1	2.91	0.29	12	15	15	1
73	9%	1	2.91	0.29	12	15	15	1
74	9%	1	2.91	0.29	12	15	15	1
75	9%	1	2.91	0.29	12	15	15	1
76	9%	1	2.91	0.29	12	15	15	1
77	9%	1	2.91	0.29	12	15	15	1
78	9%	1	2.91	0.29	12	15	15	1
79	9%	1	2.91	0.29	12	15	15	1
80	9%	1	2.91	0.29	12	15	15	1
81	9%	1	2.91	0.29	12	15	15	1
82	9%	1	2.91	0.29	12	15	15	1
83	9%	1	2.91	0.29	12	15	15	1
84	9%	1	2.91	0.29	12	15	15	1
85	9%	1	2.91	0.29	12	15	15	1
86	9%	1	2.91	0.29	12	15	15	1
87	9%	1	2.91	0.29	12	15	15	1
88	9%	1	2.91	0.29	12	15	15	1
89	6%	1	3.01	0.19	12	15	15	1
90	6%	1	3.01	0.19	12	15	15	1
91	6%	1	3.01	0.19	12	15	15	1
92	6%	1	3.01	0.19	12	15	15	1
93	6%	1	3.01	0.19	12	15	15	1
94	6%	1	3.01	0.19	12	15	15	1
95	6%	1	3.01	0.19	12	15	15	1
96	6%	1	3.01	0.19	12	15	15	1
97	6%	1	3.01	0.19	12	15	15	1
98	6%	1	3.01	0.19	12	15	15	1
99	6%	1	3.01	0.19	12	15	15	1
100	6%	1	3.01	0.19	12	15	15	1
101	6%	1	3.01	0.19	12	15	15	1
102	6%	1	3.01	0.19	12	15	15	1
103	6%	1	3.01	0.19	12	15	15	1
104	6%	1	3.01	0.19	12	15	15	1
105	3%	1	3.10	0.10	12	15	15	1
106	3%	1	3.10	0.10	12	15	15	1
107	3%	1	3.10	0.10	12	15	15	1

Shell Nr	FGMP %	Casings	Burst Powder		Lift Powder	Star (1), (2)	Gum Tape	Time Fuse
			Rice Powder 25.5 (4)	Crossette Flash (3)	5FA Black Powder (5)			
		(ea)	(g)	(g)	(g)	(g)	(ft)	(in)
108	3%	1	3.10	0.10	12	15	15	1
109	3%	1	3.10	0.10	12	15	15	1
110	3%	1	3.10	0.10	12	15	15	1
111	3%	1	3.10	0.10	12	15	15	1
112	3%	1	3.10	0.10	12	15	15	1
113	3%	1	3.10	0.10	12	15	15	1
114	3%	1	3.10	0.10	12	15	15	1
115	3%	1	3.10	0.10	12	15	15	1
116	3%	1	3.10	0.10	12	15	15	1
117	3%	1	3.10	0.10	12	15	15	1
118	3%	1	3.10	0.10	12	15	15	1
119	3%	1	3.10	0.10	12	15	15	1
120	3%	1	3.10	0.10	12	15	15	1
Test 3: 80 total complete devices with tubes								
121	12%	1	2.82	0.38	12	15	15	1
122	12%	1	2.82	0.38	12	15	15	1
123	12%	1	2.82	0.38	12	15	15	1
124	12%	1	2.82	0.38	12	15	15	1
125	12%	1	2.82	0.38	12	15	15	1
126	12%	1	2.82	0.38	12	15	15	1
127	12%	1	2.82	0.38	12	15	15	1
128	12%	1	2.82	0.38	12	15	15	1
129	12%	1	2.82	0.38	12	15	15	1
130	12%	1	2.82	0.38	12	15	15	1
131	12%	1	2.82	0.38	12	15	15	1
132	12%	1	2.82	0.38	12	15	15	1
133	12%	1	2.82	0.38	12	15	15	1
134	12%	1	2.82	0.38	12	15	15	1
135	12%	1	2.82	0.38	12	15	15	1
136	12%	1	2.82	0.38	12	15	15	1
137	12%	1	2.82	0.38	12	15	15	1
138	12%	1	2.82	0.38	12	15	15	1
139	12%	1	2.82	0.38	12	15	15	1
140	12%	1	2.82	0.38	12	15	15	1
141	12%	1	2.82	0.38	12	15	15	1
142	12%	1	2.82	0.38	12	15	15	1
143	12%	1	2.82	0.38	12	15	15	1
144	12%	1	2.82	0.38	12	15	15	1

Shell Nr	FGMP %	Casings	Burst Powder		Lift Powder	Star (1), (2)	Gum Tape	Time Fuse
			Rice Powder 25.5 (4)	Crossette Flash (3)	5FA Black Powder (5)			
		(ea)	(g)	(g)	(g)	(g)	(ft)	(in)
145	9%	1	2.91	0.29	12	15	15	1
146	9%	1	2.91	0.29	12	15	15	1
147	9%	1	2.91	0.29	12	15	15	1
148	9%	1	2.91	0.29	12	15	15	1
149	9%	1	2.91	0.29	12	15	15	1
150	9%	1	2.91	0.29	12	15	15	1
151	9%	1	2.91	0.29	12	15	15	1
152	9%	1	2.91	0.29	12	15	15	1
153	9%	1	2.91	0.29	12	15	15	1
154	9%	1	2.91	0.29	12	15	15	1
155	9%	1	2.91	0.29	12	15	15	1
156	9%	1	2.91	0.29	12	15	15	1
157	9%	1	2.91	0.29	12	15	15	1
158	9%	1	2.91	0.29	12	15	15	1
159	9%	1	2.91	0.29	12	15	15	1
160	9%	1	2.91	0.29	12	15	15	1
161	9%	1	2.91	0.29	12	15	15	1
162	9%	1	2.91	0.29	12	15	15	1
163	9%	1	2.91	0.29	12	15	15	1
164	9%	1	2.91	0.29	12	15	15	1
165	9%	1	2.91	0.29	12	15	15	1
166	9%	1	2.91	0.29	12	15	15	1
167	9%	1	2.91	0.29	12	15	15	1
168	9%	1	2.91	0.29	12	15	15	1
169	6%	1	3.01	0.19	12	15	15	1
170	6%	1	3.01	0.19	12	15	15	1
171	6%	1	3.01	0.19	12	15	15	1
172	6%	1	3.01	0.19	12	15	15	1
173	6%	1	3.01	0.19	12	15	15	1
174	6%	1	3.01	0.19	12	15	15	1
175	6%	1	3.01	0.19	12	15	15	1
176	6%	1	3.01	0.19	12	15	15	1
177	6%	1	3.01	0.19	12	15	15	1
178	6%	1	3.01	0.19	12	15	15	1
179	6%	1	3.01	0.19	12	15	15	1
180	6%	1	3.01	0.19	12	15	15	1
181	6%	1	3.01	0.19	12	15	15	1
182	6%	1	3.01	0.19	12	15	15	1

Shell Nr	FGMP %	Casings	Burst Powder		Lift Powder	Star (1), (2)	Gum Tape	Time Fuse
			Rice Powder 25.5 (4)	Crossette Flash (3)	5FA Black Powder (5)			
		(ea)	(g)	(g)	(g)	(g)	(ft)	(in)
183	6%	1	3.01	0.19	12	15	15	1
184	6%	1	3.01	0.19	12	15	15	1
185	3%	1	3.10	0.10	12	15	15	1
186	3%	1	3.10	0.10	12	15	15	1
187	3%	1	3.10	0.10	12	15	15	1
188	3%	1	3.10	0.10	12	15	15	1
189	3%	1	3.10	0.10	12	15	15	1
190	3%	1	3.10	0.10	12	15	15	1
191	3%	1	3.10	0.10	12	15	15	1
192	3%	1	3.10	0.10	12	15	15	1
193	3%	1	3.10	0.10	12	15	15	1
194	3%	1	3.10	0.10	12	15	15	1
195	3%	1	3.10	0.10	12	15	15	1
196	3%	1	3.10	0.10	12	15	15	1
197	3%	1	3.10	0.10	12	15	15	1
198	3%	1	3.10	0.10	12	15	15	1
199	3%	1	3.10	0.10	12	15	15	1
200	3%	1	3.10	0.10	12	15	15	1
Totals		200	588	52	1,920	3,000	3,000	200

All shells are spherical with a 1.75 inch diameter and have casings made of paper.

Energetic Components	
(1) Red Mag Stars	
Potassium perchlorate	38.0%
Strontium carbonate	22.0%
Magnalium 50-50 -200 mesh	19.0%
Chlorinated rubber	9.8%
Red gum	6.0%
Dextrin	5.0%
Boric acid	0.2%
	100.0%
(2) Star Igniter	
Potassium nitrate	67.5%
Sulfur	9.0%
Charcoal	13.5%
Dextrin	4.5%
Ferro titanium 40x325 mesh	5.5%
	100.0%
(3) Flash powder(crossette flash powder)	
Potassium perchlorate	70.0%
Aluminum 325 mesh	30.0%
	100.0%
(4) Rice hull burst powder	
Potassium perchlorate	66.5%
Charcoal	28.5%
Dextrin	5.0%
Composition is coated on rice hulls	**100.0%**
(5) Lift charge	
Commercial 4FA ung black powder	**100%**

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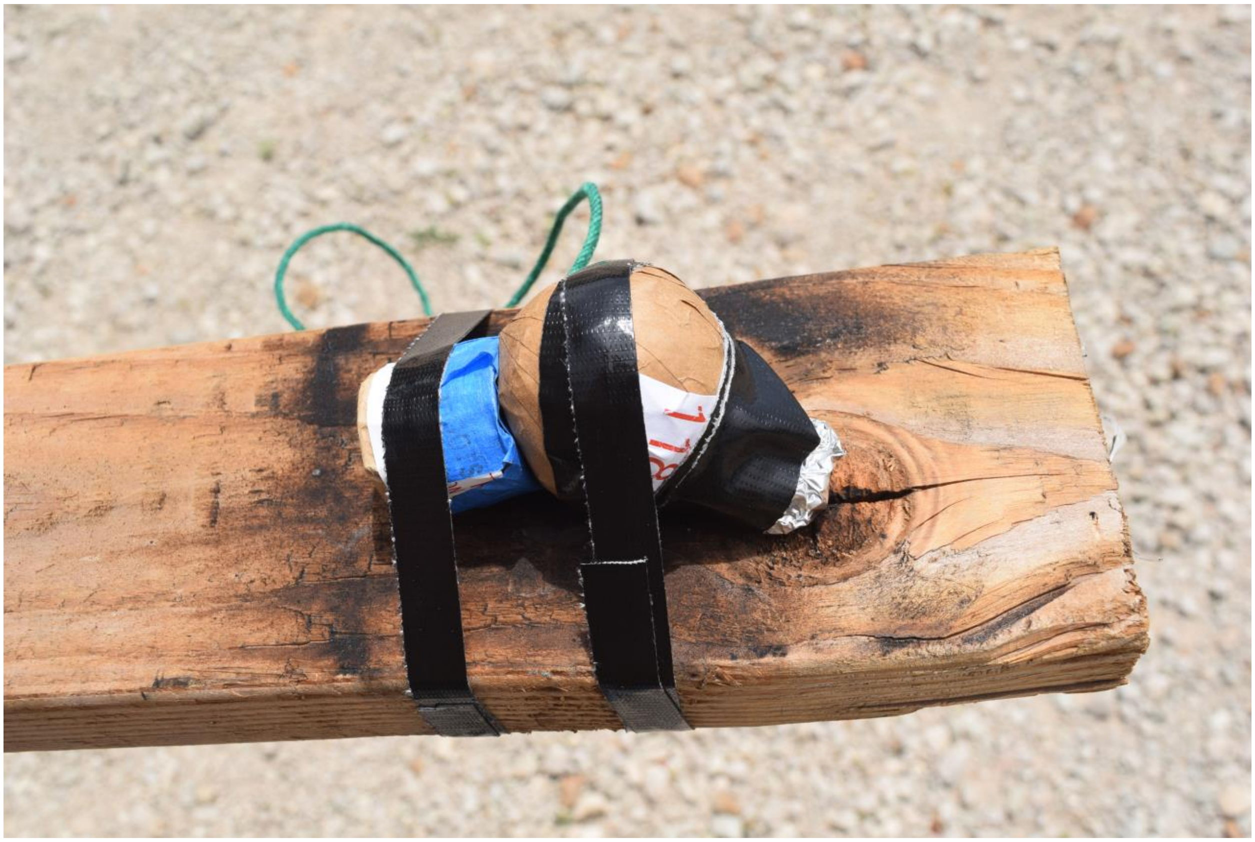
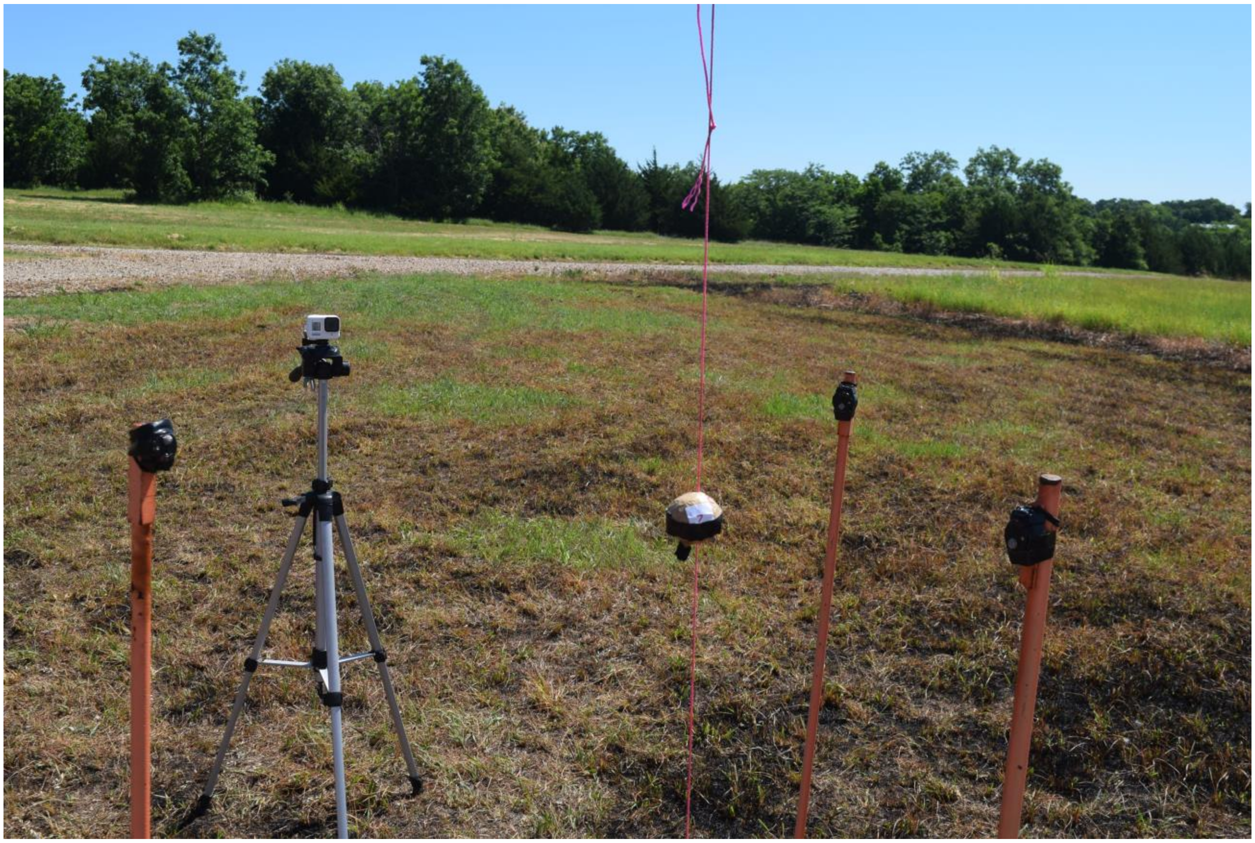
Appendix C – Photographs from Testing at OSU Explosives Research and Testing Range






2


0 1 2 3 4 5 6 7 8
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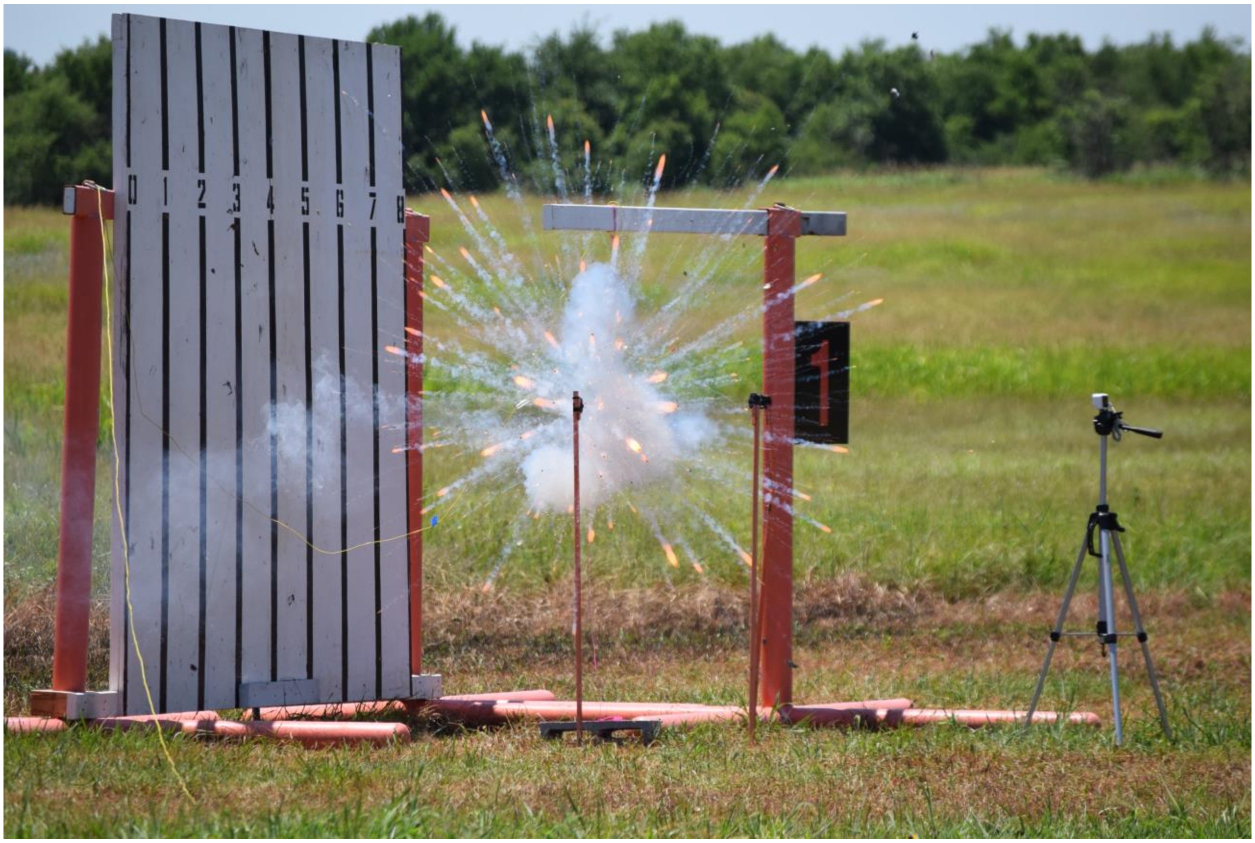
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1


2


2


2