Developing and Testing a Desensitization Process for Fireworks
Task 7 Final Report

Solicitation

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Kirt N. Sasser
A. Garn Butcher

SAFETY MANAGEMENT SERVICES, INC.
1847 WEST 9000 SOUTH, SUITE 205
WEST JORDAN, UTAH 84088
(801) 567-0456
www.smsenergetics.com

Preparation of this report by Safety Management Services, Inc. was in accordance to the terms and conditions of Solicitation PHMSA RFQ# DTPH5614Q00027.

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Principal Investigators and authors:

A. Garn Butcher
Explosive Safety Specialist

Kirt N. Sasser
Director of Testing / Classifications

Table of Contents

List of References and Attachments 5
List of Tables 6
List of Figures 7
Introduction: 10
Objective: 10
Program Outline: 10
Background 11
Executive Summary 11
Task 1: Literature Search and Test Method Selection 12
Literature Review: 12
Current Practices 13
Current Destruction Options 14
Conclusion: 19
Selection of Best Method(s) For Desensitization 19
Task 2: Proof of Concept on Desensitization Methods 21
Process Hazards Analysis and Test Procedures 21
Task 2 Overview 21
Task 2: Sample Preparation 22
Task 2: Soaking Preparation and Configuration: 25
Task 2: Sample Extraction and Examination 27
Task 2: Dissection and Condition Recording 28
Task 2: Open Fire Burning 30
Task 2: Test Results 31
Results: Maximum Percent Weight Gain 31
Results: Weight Gain Conclusions: 33
Results: Specific levels of physical deterioration 33
Conclusions for Physical Deterioration versus Soaking Solutions 41
Reaction Level Observations 42
Dried Articles: 46
Summary from Task 2 47
Task 3 Batch Process Pilot Unit Design 50

Batch Process Unit: 51
The critical features for the container are these: 53
Safety Concerns and Compliance with Task Requirements: 54
Batch Process Test Plan 55
Batch Process Unit Preparation: 56
Task 4: Testing of Batch Process Units 56
Loading Batch Process Drums 56
Sample Preparation and drum loading 58
Batch Process Loading Time 60
Testing: 60
Task 5: Results and Analysis 61
Test Results: 61
Baseline Dry Test: 62
Diesel Soak Test: 63
Water Soak Tests: 64
Batch Process Analysis and Conclusions: 65
Processing Time 65
Test Results 65
Conclusions for Batch Process Testing 66
Final Recommendation 66
Note of Concern 67
Task 6: Briefing to PHMSA 67
Task 7: Final Report 68

List of References and Attachments

Reference 1: Purchase Order #DTPH5614P00047

Reference 2: "Developing and Testing a Desensitization Process for Fireworks," SMS-3647-W1, Safety Management Services, Inc., September 11, 2014.

Reference 3: Investigation Report, "Donaldson Enterprises, Inc. Fireworks Disposal Explosion and Fire," Report No. 2011-06-I-HI, U.S. Chemical Safety and Hazard Investigation Board, January 2013

Reference 4: CSB Public Hearing, "Donaldson Enterprises, Inc. Fireworks Disposal Explosion and Fire Investigation Report," Washington, DC, U.S. Chemical Safety and Hazard Investigation Board, January 17, 2013

Reference 5: "Task 1: A Survey of Current Desensitization Methods for Fireworks and Pyrotechnic Display Articles," SMS-3647A-L1, Rev 1, March 16, 2015.

Reference 6: "Interim Report on Fireworks Desensitization, Task 2," SMS-3647-L2, Rev 1, September 18, 2015

Reference 7: "Task 3: Batch Process Pilot Plant Design and Operation," SMS-3647C-L3, Rev 1, September 23, 2015.

Reference 8: "Status Report on Fireworks Desensitization, Task D, Batch Process Testing," SMS-3647D-ST1, Rev 0, January 25, 2016.

Reference 9: "Task 5, Batch Process Test Evaluation," SMS-3647E-L4, January 26, 2016

Attachment 1: "Fireworks Desensitization Study," DOT1-3647B-HA, May 27, 2015

Attachment 2: "Fireworks Desensitization Study," SMS-3647B-TM, June 22, 2015

Attachment 3: "Fireworks Examination Definitions, 3647B-DOT1-A3

Attachment 4: "Extraction Data," 3647B-DOT1-A4

Attachment 5: "Physical Condition Examination," 3647B-DOT1-A5

Attachment 6: "Descriptions of Reactions from Fire Data," 3647B-DOT1-A6

Attachment 7: "Fireworks Desensitization Study Batch Process Procedure," SMS Operations Procedure SMS-3647D-TM, December 2, 2015

Attachment 8: "Development and Testing of a Batch Process Desensitization Method for Fireworks Program Review and Summary," 3647F-DOT1-PPT1, February 1, 2016.

List of Tables

Table 1 Destruction Options (reference ICE meeting, Ken Lantis Presentation) 15
Table 2 Methods of Desensitization Currently In Use 16
Table 3 Summary - Test Results on Variety of Desensitized Fireworks Articles/Substances 18
Table 4 Selected Fireworks/Pyrotechnic Articles for Desensitization Evaluation Testing 20
Table 5 Desensitization Methods/Solutions 20
Table 6 Task 2 Timeline for Extraction and Evaluation of Fireworks 21
Table 7: Definition of Levels of Deterioration 35
Table 8: Summary of Maximum Deterioration Reached (The lower the level, the greater the deterioration) 38
Table 9: Propulsive Component Deterioration to Level 4 or lower 40
Table 10: Star Component Deterioration to Level 4 or Lower 41
Table 11: Descriptions of Reaction Level for Fireworks Articles 42
Table 12: Week at which Sustainable Class 4.1 Reaction was Reached 44
Table 13: Quantities of Fireworks Articles in Batch Process Drums 57
Table 14: Approximate Gross Weight of All Materials in Batch Process Drums. 57
Table 15: Test Results from Batch Process Testing 61

List of Figures

Figure 1: Example of Extraction Data Log showing Item 7, 200 Gram Cake, with data used to determine solution saturation up-take and disposition of each of the articles as they were pulled........ 23
Figure 2: Firecracker bricks with zip ties and beads ready for testing 24
Figure 3: 200 Gram Cakes prepared for Diesel Solution soaking. Each article was marked with a bead and zip tie fastened around one of the aerial tubes........ 24
Figure 4: The 6-inch shells were marked on the fuze with a bead and zip tie. The plastic wrapping around each shell was breached with tears to allow solution to contact the shell directly. 24
Figure 5: Sky Rockets, removed from the exterior packaging, were marked and placed individually in the solutions. Marking beads are visible on several of these articles. 25
Figure 6: Sky Rockets in Water float but would eventually saturate and sink to the bottom of the container........ 26
Figure 7: 200 gram cakes were placed in a 57-gallon drum and covered with solution........ 26
Figure 8: The 6-inch shells were placed in a 30-gallon drum. Initially floating, the shells eventually sunk below the surface. 27
Figure 9: Containers used for soaking were labeled with solution and item number and placed in containment pans. Two pans were used for each solution. The pans were located on a concrete pad in an outside storage area........ 27
Figure 10: Firecrackers from diesel are drained on grate over the container. 28
Figure 11: 500-gram cake was tipped on its side to drain standing water from inside tubes 28
Figure 12: Description of the dissected fireworks articles were recorded in the Dissection Log. A separate table was used for each week for each solution. Description of the external condition of the article and descriptions for each of the pyrotechnic components were recorded........ 29
Figure 13: Shells were cut apart, contents examined and condition recorded. This 6-inch shell shows signs of crumbling stars after 3 weeks. 30
Figure 14: Typical burner arrangement showing an article over each burner (Sky Rocket on Left and Fountain on Right) for testing. 31
Figure 15: A typical wood pallet stack fire showing three articles, the 500-gram Cake, Firecracker Brick and a 3 inch shell........ 31
Figure 16: Percent weight gain of Small Fireworks Articles in four solutions 32
Figure 17: Percent Weight Gain of Larger Items compared in Four Solutions 33
Figure 18: Progressive deterioration of the physical condition of the articles was noted. 34
Figure 19: Diesel has the least effect of all solutions on the physical deterioration of the articles. 34
Figure 20: Dry powder in Fountain, Level 10. 35
Figure 21: Dry stars and burst in 3-inch shell, Level 10........ 36

Figure 22: Gritty powder after soaking in Diesel, Level 6 36
Figure 23: Wet but hard stars from 3-inch shell in diesel, Level 8. 36
Figure 24: Crumbly exterior with hard center from 6-inch shell in Water/Soap, Level 7. 37
Figure 25: Star from Roman Candle in Water/Soap, totally crumbly under finger pressure, Level 5. 37
Figure 26: Fountain powder from Water, totally saturated and pasty texture, Level 3 37
Figure 27: Sky Rocket powder liquefied in Water/NaOH solution, Level 1. 38
Figure 28 Table 6-A from Attachment 6 shows fire reaction data through week 6 for Sky Rocket Article in water. 43
Figure 29: Fire reaction results for the 200-gram cake soaked in diesel from table 7-D in Attachment 6. 44
Figure 30: Progression of reaction for 6-inch Shell in Diesel shows a significant change from dry to week 2 but no significant change from week 2 to week 12. Dry reaction is 1.3 and all soaked reactions are 1.4. 45
Figure 31: Progressive decrease in reactivity is quickly noted between weeks 1 and 2 in Water/NaOH moving from 1.4 to a 4.1 reaction level. 45
Figure 32: Comparison of events from 500-gram Cake at week 3 in Diesel and Water/Soap show both still throw projections over 3 feet, but Diesel reaction is much larger. 46
Figure 33: The Water/NaOH soaked 3-inch shell showed only smoke reaction at 3-week soak but returned to a 1.4 class reaction with significant fireball when dried. 46
Figure 34: The water soaked 3-inch shell showed similar results with fireball and projections after a 3-week drying period, returning to a 1.4 class reaction. 47
Figure 35: The 500-g Cake from Water after drying 3 weeks shows some tendency to Class 1.4 with 12 inch flame, similar to same article after 3 weeks soaking in Water which showed flame and some projection throw. 47
Figure 36: Typical 57-gallon plastic drum as used for conditioning/soaking of fireworks. 52
Figure 37 The 30-gallon drum was used for intermediate sized or quantities of fireworks. 52
Figure 38 The 5- or 6-gallon containers have the following description: http://www.usplastic.com/catalog/item.aspx?itemid=33033&catid=752 53
Figure 39: Typical Fireworks articles as received in vendor/manufacturer’s packaging 58
Figure 40: 3-inch shells as received in vendor packaging. 59
Figure 41: Bottom layer with shells and large cakes. Order of loading was not specific. Materials were placed to take up space. 59
Figure 42: Additional packaged and unpackaged articles added to container. 59
Figure 43: Full container ready for addition of soaking solution. 60
Figure 44: Full containers were photographed and documented. 60
Figure 45: Fire stack arrangement typical for the batch process tests. 61
Figure 46: Baseline dry shells event with 6 inch shell. Dark object above screens is the drum that was blown up into the air. 62

Figure 47: Baseline dry small fireworks event shows areal burst (red stars) in upper center of frame. 63
Figure 48: Exploding aerial effect from 500 g cake near camera at 150 feet from fire. 63
Figure 49: Maximum event from Diesel fire throws effects about 15 feet. 64
Figure 50: Maximum event from water soaked fireworks shows that drying will allow materials to burn. 64

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Pipeline and Hazardous Materials Safety Administration January 28, 2016
1200 New Jersey Avenue, SE
Washington, D. C.

Attn: Dr. Richard Tarr

Subject: Developing and Testing a Desensitization Process for Fireworks, Task 7 Final Report

Introduction:

This is the final report for contract #DTPH5614P00047 from the US Department of Transportation, Pipeline and Hazardous Materials Administration (PHMSA) to Safety Management Services, Inc. (SMS) The Contract was issued to SMS to develop a desensitization process for fireworks. Fireworks include both commercially available consumer fireworks as well as fireworks for technical display only. Operations, proposals and test plans including interim reports have been reviewed and approved by the Contracting Officer Representative (COR) of PHMSA throughout the period of this contract.

Objective:

The objective of this effort is to develop a method or methods of batch processing to desensitize fireworks that will at a 95% confidence level render them to a hazards classification of UN3380, Desensitized explosives, solid, n.o.s. 4.1. The evaluation will provide evidence that this goal can be achieved. If this goal cannot be achieved, the evaluation will provide evidence of the realistic expectation of the maximum degree of desensitization that can be achieved.

Program Outline:

The program is comprised of seven tasks as listed:

- Task 1: Evaluation of Process Technologies
- Task 2: Demonstrate "Proof of Concept or Concepts"
- Task 3: Design and Build Pilot Process
- Task 4: Batch Trial Testing
- Task 5: Data Analysis of Batch Trial Tests
- Task 6: Briefing to PHMSA
- Task 7: Final Report and Presentation

Each of the seven tasks will be addressed in this final report.

References and support documentation are identified in the References and Attachments page. Attachments pertinent to this report will be provided as individual digital files and/or hard copies as needed. Interim reports on various tasks have already been submitted. These documents appear in the reference list. A complete set of still photos and videos will also be made available on separate digital recording media.

Background

The need for this project was due primarily on the findings from the U.S. Chemical Safety and Hazard Investigation Board's (CSB) investigation into the Donaldson Enterprises, Inc. (DEI) Fireworks Disposal Explosion and Fire that resulted in the death of five DEI employees on April 8, 2011 (Ref 3). The following is a summary as pertaining to the regulatory or standards currently available for proper disposal of fireworks (Ref 4):

> "The CSB found that there is a substantial regulatory gap that exists pertaining to fireworks disposal. The CSB could not identify any regulations or standards that establish adequate safety requirements, provide guidance on proper ways to dispose of fireworks or address the hazards associated with the disassembly of fireworks and the accumulation of explosive firework components. For example, the National Fire Protection Association (NFPA) has created safety standards governing fireworks display, storage and manufacturing; however, none address the safe disposal of fireworks."

As seen from the CSB findings where extensive research was performed, there is no current approved or recommended method for disposing of fireworks.

Executive Summary

Task 1 research found that there have been no systematic studies on the effects of different solutions to desensitize fireworks or loose pyrotechnic materials. Research into current practices for desensitizing fireworks identified use of various water based solutions, diesel and vegetable oil saturation and some chemically reactive solutions such as acetone. No specific machinery or hardware was identified for the exclusive use of desensitizing fireworks. Actual data on several of these solutions was obtained and some testing was witnessed by SMS personnel. The results of this investigation lead to the identification of soaking fireworks in a desensitizing solution as the most probable means of reaching the project objective. Based on the research, four different solutions were identified for evaluation. These included Water, Water/Soap, Water/Sodium Hydroxide (NaOH) and Diesel. The chemically active solutions were deemed as too hazardous for common use and thus eliminated from consideration. Hazards included toxicity and flammability.

Task 2 experimentally determined the effects of different solutions on fireworks in the following three primary areas: Weight gain by saturation of the article, Physical deterioration of the pyrotechnic components and overall reaction level in a fire with a goal of reaching a behavior that can be classed as a Flammable Solid, 4.1.

Task 2 results indicate that weight gain from solution up-take reaches near maximum in all articles in the first week. Only small additional gain in weight is noted in subsequent weeks.

The NaOH appears to be the solution providing the greatest overall weight gain. Water and Water/Soap are very similar but slightly less effective than Water/NaOH. Diesel provides the least weight gain. Diesel is also the slowest to achieve a maximum weight gain.

Physical deterioration is most significant in the Water/NaOH solution with Water/Soap being the next most destructive. Diesel does little or no damage to the article or to the pyrotechnic stars in the article. All solutions will saturate the powder components of the articles. Diesel and Water did little to the pressed stars.

Reactivity is significantly reduced in all articles after one week of soaking in any of the four solutions. All articles are at least at a 1.4 or 4.1 level of reactivity after the first week. All articles in the water based solutions achieve a 4.1 level of reactivity generally after the third or fourth week with the larger articles requiring up to six weeks. Only two of the articles, the Fountain and the Sky Rocket achieved a 4.1 level of reactivity in the Diesel. All other Diesel soaked items remained at a 1.4 or 1.4S level of reactivity.

Drying the 500-gram cake and 3-inch shells for three weeks in open air showed that article may return to a 1.4 level of reactivity if sufficiently dried out.

Task 3 defined and developed a batch process unit capable of desensitizing fireworks to the desired hazard level in quantities of up to 100 pounds. A test plan was developed based on Task 2 results to desensitize and test fireworks in two solutions, water and diesel.

Testing was successfully performed under Task 4 with the analysis of Task 5 showing that water will provide adequate desensitization to achieve the 4.1 Hazards class behavior. Diesel, also tested, will achieve a 1.4 Hazards class behavior. Drying out fireworks will return the hazards behavior from 4.1 to 1.4 from desensitization in water based solutions.

Task 1: Literature Search and Test Method Selection

Task 1 was a survey of current desensitization methods for fireworks and pyrotechnic display articles. It focused on obtaining information about application of methods to desensitize fireworks and results of any systematic studies on this process.

Literature Review:

A significant dilemma exists with respect to proper desensitization of unused, unexploded and damaged fireworks and pyrotechnic display articles so they can be safely handled and transported for disposal. There are published papers dealing with the “hazards” of handling these items and there are numerous “opinions” on how to safely desensitize and dispose of these items. However, there are few if any official publications from government, academic or commercial resources giving approved procedures for this process.

The basic concern is in determining a suitable means to render these articles safe to handle and transport. Unpackaged, damaged or unfired pyrotechnic articles present the possibility of increased hazards to the handlers due to potentially exposed or altered pyrotechnic components.

"Duds" or unfired devices may have residual pyrotechnic with an undefined sensitivity to impact, friction or electro-static energy.

Current Practices

Research conducted by Safety Management Services, Inc., (SMS) has discovered a wide range of opinions and advice regarding the proper disposal procedure for fireworks. Unfortunately, the majority of these statements are related exclusively to consumer fireworks. There is a wide range of advice, some of which seems contradictory and even dangerous. The following are typical positions on how to dispose of fireworks:

- Most common is to soak questionable, unused or dud fireworks in a bucket of water. However, length of soaking as recommended by a number of emergency response fire department personnel ranges from 5 minutes to 5 days. The majority of responses on length of time suggest 24 hours. This could be based on two procedures published by The Fireworks Alliance (TFA) and the American Pyrotechnics Association (APA), both of which give the suggested time of 24 hours soak time. Disposal is then to put them into plastic garbage bags and dump them in the household trash.
    - http://www.fireworksalliance.org/cgi-bin/viewpage.pl?p=safety
    - http://www.americanpyro.com/backyard-fireworks-tips
    - http://www.rentonreporter.com/news/265748791.html
    - http://www.ehow.com/how_8117852_rid-fireworks.html
    - http://www.maine.gov/dep/how-do-i/how-do-i.html?id=440736
    - http://www.cpsc.gov/en/Safety-Education/Safety-Education-Centers/Fireworks/
    - https://vimeo.com/67793259

- For unused fireworks, several sources recommended removal of the fuse from the article then placing it into a bucket of water and soaking for 20 minutes. Articles are then to be put in a plastic trash bag and set out to the household garbage. Removal of fuses from live fireworks seems to defy good safety practices. Also, no advice on how to remove the fuse is given – other than to grab it with your fingers and pull it out.
    - http://www.wikihow.com/Dispose-of-Fireworks
    - http://kezj.com/how-to-properly-dispose-of-used-fireworks/

- Another published source recommended that fireworks should never be put into water as this may cause a destabilization of the pyrotechnic which could lead to unexpected detonation of the device (official bulletin from a California county).
    - http://www.mercergov.org/Page.asp?NavID=2335

- Many suggested that unused and undamaged fireworks should be taken to the local fire department for disposal. Others suggest that if one encounters a pyrotechnic article – Call 911.
    - http://www.ci.minneapolis.mn.us/solid-waste/whattodo/solid-waste_what-to-do-f

- SMS also searched the Approvals Data Base of the US Department of Transportation, PHMSA web page for current Competent Authority Approvals of waste explosives and fireworks to gain insight into what methods have been approved for the desensitization of these materials. SMS found that only a handful of approvals have been granted. These are primarily to pyrotechnic manufacturers and large volume users who would generate a sizeable quantity of waste materials on a regular basis. SMS also looked at desensitized explosive wastes since the hazards of these materials are similar to those of pyrotechnics and fireworks.

  - https://hazmatonline.phmsa.dot.gov/ApprovalsSearch/Search.aspx

- SMS located a number of disposal services that claim to offer disposal of unwanted fireworks. Of these, only one was a significant user of fireworks. The other service providers did not have any direct connection to a display or manufacturer. Based on a search of PHMSA's approvals data base, none of these companies had been issued any shipping approvals of any kind. It could be that they are approved for shipping though other organizations, or a branch of their respective companies who deals in pyrotechnics, but it was not obvious that these disposal companies held any CAA's for shipping waste fireworks. Our experience working with such companies is that they require approval to be obtained by the owner of the fireworks/waste before transporting, thus they would not have any CAA's in their name. In all of the research for disposal companies, there were no indications of how the materials were disposed of or if they were desensitized prior to shipping to a disposal location.
  - http://www.fireworksdisposal.com/?gclid=CMq-k6eEgMQCFYY9aQodeikAkQ
  - http://www.cleanharbors.com/
  - http://superiorpyro.com/index.php?page=disposal

Current Destruction Options

Information obtained by SMS concludes that in general, everyone is concerned, but there is little or no published data on the effectiveness of desensitization methods for fireworks and pyrotechnic articles. One of the more comprehensive collections of information was from the Interagency Committee on Explosive (ICE) meeting, held April 23, 2013 in Washington D.C. Participants included government agencies and industrial representatives from the manufacturing, display, disposal and testing community. Several papers were presented that outlined the problems of dealing with these waste materials and primarily concentrated on what is not available with respect to disposal options and what is not available on direction or procedures for handling and desensitizing waste materials. One paper offered several options on the disposal of the materials and two papers dealt with actual field operations on desensitizing various pyrotechnic articles.

Based on the research and discussions with authorities and manufacturers/handlers of pyrotechnic and fireworks waste materials, SMS offers the following summary of means by which these materials may be handled, desensitized and/or destroyed. Table 1 discusses the destruction options currently available. Table 2 discusses the desensitization methods currently in use.

Table 1 Destruction Options (reference ICE meeting, Ken Lantis Presentation)

Method	Implementation	Pro's	Con's
Open Burn/Open Detonation	Use of a remote facility to burn/detonate as-is pyro waste	Easily implemented, relatively effective, low cost	Requires significant land and remote facility, air pollution, ground pollution residual, may present significant hazard to handlers with large quantities of material to be processed, requires primarily dry pyrotechnic condition for maximum effectiveness
Closed Incinerator Burn	Use of remote facility and closed equipment to burn in a furnace or other enclosure.	Contained burn, may implement scrubber to minimize pollution, controlled quantities, may handle wetted pyrotechnic materials better than open burn because of auxiliary fuel source	May require disassembly of large pyro articles, considerable facility expenditure, limited thru-put, thus may be time consuming, increased hazard to handlers to place and distribute materials into incinerator.
Remediation	Mixing of wastes with diluents such as soil or sand, then cooking them in low heat to slowly decompose pyrotechnics	Minimize pollution generated, low hazard once operation is started	Increase hazard to operators during preparation of materials, considerable expense for operating hardware, time consuming
Enzymatic Degradation	Expose pyrotechnic components to enzymes, bacteria to degrade and destroy composition	Moderate hazard to operators, environmentally friendly as no smoke or other pollutants generated, chemical nature of components is destroyed	Very time consuming, chemical breakdown limited, all chemicals may not be affected, unproven effectiveness

Table 2 Methods of Desensitization Currently In Use

Method	Implementation	Current Recommended Treatment Period	Pro's	Con's
Water Soaking	Place articles and substances in water	5 minutes to three weeks	Safe and easy, little peripheral expense, immediate desensitization upon contact with powder, near complete reduction of reactivity on wet materials, no special equipment needed, moderate hazard to operating personnel, acceptable method per DOT CAA's, most complete desensitization method observed by SMS experience in testing	May generate some off-gassing if contact with fine aluminum and magnesium powders, water level and total submersion is necessary, soaking into tightly sealed articles may be ineffective or time consuming, generates a water soaked article for final disposal which may present problems with disposal facilities, once wet, must be kept wet or residual dry precipitates may be formed having unknown sensitivity, no published data on period of soaking to be 100% effective.
Water soaking with added surfactant (Soap)	Same as water soaking but with added surfactant to facilitate penetration of water into tightly configured articles	No specific recommendation on time. Method was presented in interviews with fire department personnel	Same as with water soaking but may reduce time to effectively desensitize tightly wrapped articles	No specific data on effectiveness
Diesel oil soaking	Pyrotechnic articles and substances are placed in container with diesel oil	No specific time of soaking is identified. Experimental results vary. Suggestion of 1-3 weeks has been made	Little or no off-gassing generated, significantly reduces reactivity, presents a condition allowing for good burn at destruction facility, little or no hardware expense	Slightly more costly than water due to fuel expense, presents a storage problem with flammable liquids and pyrotechnic, will not completely render pyrotechnic non-reactive, may not render tightly wrapped or configured articles non-reactive, soaking time is undetermined for large articles or tightly wrapped articles
Vegetable oil, motor oil, glycol	Soaking in various oils with lower ignition temperatures than diesel	No recommendations are available for this method of soaking for fireworks. Vegetable oils are commonly used	Similar to diesel with less of a flammable liquid hazard, most effective for loose materials such as stars, pellets, powders, etc., more	Longer soak time due to lower penetration ability, effectiveness unproven on large scale or wide variety of articles.

Method	Implementation	Current Recommended Treatment Period	Pro's	Con's
		for desensitizing explosives and pyrotechnics used in other than fireworks and for some articles such as ammunition primers, squibs, initiators	easily burned in destruction operations than water wet materials	
Acetone wetting	Submerge pyrotechnic materials in acetone	No specific recommendation or conditions are available. Use of this method was specific to possible chemical destruction of the pyrotechnic composition	May destroy the pyrotechnic composition chemically, reducing the hazard.	Very flammable condition, volatility is very high, thus drying is an issue, may not destroy chemicals completely, did not significantly reduce the reactivity of pyrotechnics soaked for 7 days in solution, costly.
Vacuum infusion	Place pyrotechnic articles in water in vacuum chamber, then pull vacuum to remove air and suck water into article as air is removed	No recommended procedures exist. This is a prototype method under investigation	More effective infusion of water into pyrotechnic article, may reduce soak time	Costly hardware, small batch capability, currently unproven effectiveness over nominal ambient soak, although soak time may be reduced the small batch capability could ultimately increase time to treat large quantities of articles, increased hazard of handling due to complexity of hardware assembly/disassembly
Chemical Treatment	Soak pyrotechnic and fireworks in chemical solution designed to destroy the pyrotechnic to render it inert. Solutions may involve caustic soda ash, sodium hydroxide, other	No specific treatment procedures available, some proprietary information identified, but not accessed	Effective in rendering explosives inert upon direct exposure, most effective for exposed powder or pellets	Unknown ability to treat unexposed composition in articles, chemical hazards of solution, unknown ability to render all pyrotechnic components inert, unknown ability to penetrate pressed pellets containing rubber binder components, unknown byproducts of decomposition, potential environmental impact, unknown cost but likely expensive for large scale treatment

The outcome of the research done thus far is that little data is available to demonstrate the effectiveness of the various treatment methods on a wide range of pyrotechnic substances. There is even less data on the treatment and disposal of pyrotechnic articles. Substances are easily desensitized. Contact directly with the desensitizing agent is immediate and effective on substances or loose pyrotechnic materials. All fluids mentioned in table 2 are effective in reducing reactivity. Aqueous solutions are effective based on SMS trials using 5-gallon pails of loose substances soaked in water, diesel, vegetable oil and acetone. A summary of SMS's experience is provided in Table 3.

Table 3 Summary - Test Results on Variety of Desensitized Fireworks Articles/Substances

Type of Fireworks	Soaking Solution	Soak Time	Classification Behavior
Fireworks articles, mines, small shells, fountains, 1.0 to 4.0 inches	Diesel	3 weeks	In steel container – 1.4G – 1.3G In plastic – 1.4G
Fireworks articles, mines, small shells, fountains, spinners, roman candles	Water	7 days	In plastic 30 gallon drum, 1.4G with nominal 4.1 behavior for most events. Approx 30 minute consumption time. The 1.4G recommendation was based in part on uncontrollable condition of articles in a waste stream.
Aerial Shells 3-10 inch	Diesel	7 days	1.4G
Aerial Shells 3-10 inch	Water	7 days	1.4G for 6 inch and larger. 1.4G to 4.1 for up to 6 inch. Recommended Classification as a group – 1.4G
Loose pyrotechnic waste materials	Diesel	7 days	1.4G behavior, 25 second burn time on 5-gallon metal container
Loose pyrotechnic waste materials	Vegetable oil	7 days	1.4G behavior, 79 second burn time on 5-gallon metal container
Flash powder compositions	Diesel	2-3 hours	4.1 desensitized explosive, 4.1 behavior, 20 minute consumption in 5-gallon container
Flash powder compositions	Vegetable oil	2-3 hours	4.1 desensitized explosive in 1 gallon containers – 10 minute consumption
Flash powder compositions	Glycol	2-3 hours	4.1 desensitized explosive in 1 gallon containers, 10 minutes plus consumption

General observations:

- Diesel will desensitize articles and substances to 1.4G behavior with 7 to 21 days soak.
- Water will desensitize articles to 1.4/4.1 behavior in as little as 7 days depending on the type of article. Reactivity is significantly less with a water soak than with a diesel soak, even when diesel soak time is longer.
- Vegetable oil is similar to diesel.
- Glycol is similar to water.

Powdered substances are significantly less reactive when soaked or even immediately saturated with diesel, vegetable oil or glycol. Behavior of saturated powders in diesel or vegetable oil is typical of 4.1. Testing with water was not performed.

No data is available on how long it takes to render compete non-reactivity of pressed or formed pellets. Coating with water, diesel or oils will reduce reactivity, but may not render the materials inert. If they dry out, reactivity may return. The more volatile the desensitizing liquid, the less effective a long term solution they offer given the potential to dry out.

Articles are typically more challenging to desensitize because of the construction of the article. Casings, caps and plugs in the article limit the ability of the desensitizing agent to penetrate and reach the pyrotechnic components. The materials of construction of the article will also have impact on the time required for desensitizing agent to reach the pyrotechnics. The tighter wound the article or more limited access to the interior is, the more difficult to desensitize by soaking. Good examples are shells which are impermeable other than through a fuse port or by extended soaking to get through the tough outer casing, thus significantly limiting the ability to soak into the device. Limited data is available to determine what length of soak time is effective. It has been shown that soaking in any of the above mentioned liquids will have some effect, but water appears to be the most effective. Chemical solutions are exempt from a complete evaluation at this time since virtually no data is available on treatment solutions. Diesel, although effective in reducing reactivity will not completely render the articles non-reactive. Explosive events have been observed from diesel soaked articles. The effect of time of soaking has not been investigated, thus data is limited. Effectiveness may be improved with additional soak time.

Conclusion:

SMS found that there are no systematic studies of the effectiveness of desensitization methods used. There are no systematic studies on the length of exposure to a desensitization material to render a fireworks article inert or minimally reactive at a 95% confidence level. Although there have been a number of tests to show that certain methods do appear to render fireworks less reactive, this data is not published in open literature and is restricted in application to a specific pyrotechnic article with no data extrapolating to various fireworks types. Most tests were intended to merely show a reduction in reactivity after treatment and not to provide definitive data on the methodology itself or the details of how to apply the methodology.

Selection of Best Method(s) For Desensitization

SMS recommended in concurrence with direction from PHMSA that a systematic study be conducted to better identify the methodologies and effectiveness of methodologies for desensitization of various fireworks articles. SMS selected a variety of fireworks and pyrotechnic articles to be evaluated. Selection of desensitizing solutions was also made based on the research performed in Task 1. The fireworks selection is shown in Table 4. Table 5 provides the proposed desensitization methods/solutions to be implemented. Details of the plan are provided in the Task 2 section of this report.

Table 4 Selected Fireworks/Pyrotechnic Articles for Desensitization Evaluation Testing

Item	Firework or Pyrotechnic Article	Description
1	Firecrackers	Single Bricks (80 x 16)
2	Cylindrical Fountain	Single Tubes (75 gram load)
3	Roman Candle	1" diameter tubes (20 gram load)
4	Bottle Rocket	With report (12-Packs)
5	Bottle Rocket	With whistle (12-Packs)
6	Sky Rocket	(20 gram load)
7	Cake	(200 gram)
8	Cake	(500 gram)
9	3" Shell (Kraft paper)	
10	6" Shell (Kraft paper)	With internal components other than "willows"(i.e., stars, comets, or other propelling components)
11	3" Shell (plastic)	Found to be not in production, thus this item was dropped from the original proposed matrix
12	10" Shell (Kraft Paper)	Found to be not available in a timely manner thus this item was dropped from the original matrix. It was determined that sufficient data were obtained from the 3" and 6" shells to extrapolate to the larger shells.

Table 5 Desensitization Methods/Solutions

Solution	Mixture
Water	100% water
Water with added surfactant	95-99% Water, Surfactant (dish soap) sufficient to release surface tension
Diesel	100% diesel fuel
Caustic Solution	TBD, First choice = Sodium Hydroxide – 5% with optional surfactant added

Task 2: Proof of Concept on Desensitization Methods

Task 2 is the implementation of the proposed efforts from Task 1. This task is a "proof of concept" task to evaluate the effectiveness of various solutions selected in Task 1 to desensitize the variety of fireworks selected for the evaluation.
Process Hazards Analysis and Test Procedures

Before beginning the actual process of testing and evaluating the fireworks, a complete process hazards analysis was performed according to requirements of MIL-STD-882C on the proposed operations. A detailed report, "Fireworks Desensitization Study," DOT-3647B-HA, 27 May 2015, including the failure modes and effects evaluation is included as Attachment 1. An operating procedure was also written for the preparation and handling of the fireworks. This document, "Fireworks Desensitization Study," SMS-3647B-TM, 22 June, 2015, is included as Attachment 2. Specific attention was paid to the findings of the hazards analysis in development of the procedure to address the unique hazards of the proposed operations. No specific safety related findings were identified that would need special provisions beyond that which is already in place through the standard operating procedures of the test facility and the specific operating procedure for these tasks.

Task 2 Overview

Test articles from Table 4 were placed in each of the four solutions from Table 5. Data obtained included weight gain by uptake of solution into the article, physical condition of pyrotechnic content and reactivity on a fire. Testing was performed at one-week intervals for eight weeks, and again at week 12 for selected articles. Table 6 provides a time line of activities associated with the testing and evaluation of the fireworks.

Table 6 Task 2 Timeline for Extraction and Evaluation of Fireworks

Week(s)	Steps	Activity
0	1	Photograph and weigh all articles
	2	Dissect one control article for each article type in Table 1
	3	Perform fire test on one control article for each article type in Table 1
	4	Place articles into soaking baths
1-8	5	Photograph and weigh articles removed from soaking baths (two of each type from each solution)
	6	Dissect one control article for each article type in Table 1
	7	Perform fire test on one control article for each article type in Table 1
	8	Based on test results determine effectiveness of length of soaking and determine if continued soaking is required
	9	Repeat steps 5-8 as necessary
12	10	Photograph and weigh articles removed from soaking baths (two of each type from each solution)
	11	Dissect one control article for each article type in Table 1
	12	Perform fire test on one control article for each article type in Table 1

New articles were tested for a baseline. One of each article in Table 4 was dissected as a control without any treatment. One of each article was burned on a fire to show the untreated reaction behavior.

All articles for desensitization were placed in the respective solutions on the same day, June 2, 2015. Only like articles were placed in a container to minimize potential cross contamination effects. At one-week intervals, two articles of each type from each solution were extracted, photographed and weighed. One of the articles was dissected to determine the extent of solution penetration and condition of the pyrotechnic inside. Multiple photos were taken of each article to show the extent of saturation and physical change. A log on the description of each article was also kept.

The other article was burned on either a propane fire or a mass wood fire (depending on the article size) to determine the change in reaction. The fires were videoed with two cameras at different angles to observe the results. Once a fire method was selected for an article it was used throughout the matrix. For example, all sky rockets were burned on a propane fire and all shells (3 and 6 inch) were burned on a wood fire. The only exception was the firecrackers. Initially, these were burned on a wood fire due to the size of the brick of firecrackers. At week 2, one or two individual 50 count packets were removed from the brick and placed on a propane fire to get a better idea of how they were reacting as the wood fire generally obscured the reaction. The remainder of the brick was burned on the wood fire.

A massive amount of data has been recorded for this project including a description of each article from each solution at each pull interval, photos of all articles as they were removed from the solutions, photos of the internal conditions as they were dissected and photos of the reaction on the fires. Video of each fire showing reactions included an overhead camera and a ground level camera with sound. Logs were kept to show changes in weight at each pull. Data have been compiled to show the progression of saturation and physical deterioration for each article in each solution. Since the amount of data is significant, only a few selected pieces of data are shown as representative of the effects observed on all articles. A complete compilation of data including photos, videos and analytical tables are available on the provided portable hard drive as deliverables for this project. Summary of the results will be provided in as complete and comprehensive a form as possible in the tables and charts presented in the document.

To assist in the tracking of the condition and reaction of each article a set of basic definitions were established. The definitions include standard terminology for the condition of the pyrotechnic powders, stars and exterior casing. Terminology was also defined for the reaction behavior to be consistent with criteria used to classify hazardous materials in Class 1 and Class 4. These terms and definitions are presented in Attachment 3.

Task 2: Sample Preparation

Each sample was tagged with a unique color code identifier consisting of a plastic bead and a zip tie. The article was weighed and the information recorded in a log book. A separate section in the log book was devoted to each of the four solutions. As the articles were extracted from the solutions on each successive week, they were identified by this color coding and data recorded appropriately. An example page from the log book is shown in Figure 1. The complete log book is contained in Attachment 4.

Item 7: Cake "Tough Stuff" (200 g) in Water							
Article Identification[1]			**Dry Weight (grams)**	**Week Extracted Date Extracted**	**Wet Weight (grams)**	**Net Change (grams)**	**Used for**
Marked Number	**Zip Tie**	**Bead(s)**					
1	Yellow	Red	1006	2 June 16	1720	714	Dissection
2	Yellow	Red-Orange	993	1 June 9	1604	611	Burn
3	Yellow	Orange	989	2 June 16	1649	660	Burn
4	Yellow	Blue	995	5 July 7	1735	740	Dissect
5	Yellow	Vista Blue	990	7 July 21	1752	762	Burn
6	Yellow	Sky Blue	989	5 July 7	1754	765	Burn

Figure 1: Example of Extraction Data Log showing Item 7, 200 Gram Cake, with data used to determine solution saturation up-take and disposition of each of the articles as they were pulled.

Note: Sequence of extraction is not necessarily in the order of the marked numbering of the article. Articles were pulled randomly from each container and identified by the color coding bead and zip tie. Data for that article was written in the table when it was extracted.

A set of articles was marked and catalogued for each of the solutions. Figures 2 – 4 show some examples of this process.

Figure 2: Firecracker bricks with zip ties and beads ready for testing

Figure 3: 200 Gram Cakes prepared for Diesel Solution soaking. Each article was marked with a bead and zip tie fastened around one of the aerial tubes.

Figure 4: The 6-inch shells were marked on the fuze with a bead and zip tie. The plastic wrapping around each shell was breached with tears to allow solution to contact the shell directly.

Several of the articles were packaged in boxes or packets with external wrapping such as plastic or sealed film. These external wrappings were removed as they would otherwise protect the fireworks article from exposure to the soaking solution. If there was an internal plastic wrapping or bag around the individual articles or a group of articles it was breached with tears or cuts to allow the soaking solution to penetrate and contact the article directly. An example was the Sky Rockets that were packaged in cardboard box and wrapped with a plastic film. The Sky Rockets were removed from the packaging and placed individually in the solutions. The configuration of these articles ready for placement in the solutions is shown in Figure 5. The marking beads are clearly identifiable on several of the articles in this photo

Figure 5: Sky Rockets, removed from the exterior packaging, were marked and placed individually in the solutions. Marking beads are visible on several of these articles.

Task 2: Soaking Preparation and Configuration:

Articles were placed in various sized containers depending on the size of the articles. The smaller articles were placed in 5-gallon containers. The intermediate sized articles were placed in 30-gallon drums and the largest article – the 500 gram cake – was placed in 57-gallon drums. Only one type of article was placed in a given container to prevent any cross contamination potential. Multiple containers may have been used for a given article, such as the 500-gram cake because all articles would not fit in one container. Placing only one type of article per container also facilitated removal and tracking of the articles. Sufficient solution was added to each container to allow complete submersion of all articles in the container. Lids were placed on each container and secured. A small hole was drilled in each lid to allow for air and any gas byproducts produced during the saturation period to escape. This prevented any unsafe condition of gas build up to occur.

Solution preparation for each mixture involving more than one component was done in 30-gallon batch processes. The Water/Soap and the Water/NaOH were each mixed in 30-gallon batches by predetermined ratios of additives. An experiment was used to determine the optimum ratio of soap for the water to break the surface tension and allow for optimal penetration into the fireworks articles. It was determined that approximately 30 grams per 30 gallons of water gave adequate performance. As a margin, this amount was doubled to 60 grams per 30 gallons to assure best results. The NaOH was measured at 5% by weight. The mixed solutions were bucketed out of the mixing drum to fill the 5-gallon, 30-gallon and 57-gallon containers. This method of mixing assured a consistent solution for all the articles regardless of the size container used.

The articles were placed in the containers and then the soaking solution was added. A short period of time was allowed for air to escape the article and additional solution as added to "top-off" the drum. Figures 6-10 so examples of the different articles in their containers with soaking solutions added.

Figure 6: Sky Rockets in Water float but would eventually saturate and sink to the bottom of the container.

Figure 7: 200 gram cakes were placed in a 57-gallon drum and covered with solution.

Figure 8: The 6-inch shells were placed in a 30-gallon drum. Initially floating, the shells eventually sunk below the surface.

Each set of containers for a given soaking solution were placed in spill-containment pans and set on a concrete pad. Two containment pans were used for each solution. Figure 9 shows this layout. Each container was labeled with the solution and the item number (from Table 1) it contained.

Figure 9: Containers used for soaking were labeled with solution and item number and placed in containment pans. Two pans were used for each solution. The pans were located on a concrete pad in an outside storage area.

Task 2: Sample Extraction and Examination

Upon extraction, the articles were placed on grates over their respective containers to drain off excess liquid. This allowed the articles to be examined based on the retained weight of solution that was taken into the packaging and pyrotechnic materials. No set time limit was used in the draining process. Articles were left until it was obvious that the majority of free liquid had drained off. Figures 10 and 11 show examples of this process.

Figure 10: Firecrackers from diesel are drained on grate over the container.

Figure 11: 500-gram cake was tipped on its side to drain standing water from inside tubes

After the samples had drained they were placed on transport trays or in buckets and taken to the lab. At the lab, each sample was weighed and the weight recorded in the log book. The net weight gain was calculated and entered into a data table. One sample was set aside for burning and the other was dissected and condition of the article catalogued.

Task 2: Dissection and Condition Recording

Description of the condition of each article was recorded. Initially it was intended to record this information in the weights and color coding log (Attachment 4), however it quickly became evident that space in that log book was insufficient. Therefore a second log was initiated to record the condition of the various components of each article. An example page of this recording is shown in Figure 12. The entire dissection log is provided as Attachment 5. Definitions of the terminology are recorded in Attachment 3.

3647B-DOT1 EXAMINATION TESTING PHASE I

DESENSITIZATION LIQUID: ____**Water**______ WEEK: ____**1**________

ITEM 1 – **FIRECRACKERS**

COMPONENT	WETTNESS	PHYSICAL CONDITION
OUTER PAPER	Sat	Soft
POWDER	Wet	pasty

ITEM 2 – FOUNTAINS

COMPONENT	WETTNESS	PHYSICAL CONDITION
OUTER PAPER	Sat	Soft
CLAY	Wet	Soft
POWDER	Sat	pasty

ITEM 3 – ROMAN CANDLES

COMPONENT	WETTNESS	PHYSICAL CONDITION
OUTER PAPER	Sat	Soft
LIFT - SECTIONS	Sat	soft
STARS	Sat	Soft (#2 not checked)
CLAY	Wet	Crumbles
FIRECRACKER BETWEEN STARS	Damp	firecracker pasty

ITEM 4 – BOTTLE ROCKETS – SMALL

COMPONENT	WETTNESS	PHYSICAL CONDITION
OUTER PAPER	Sat	Soft
MAIN PYRO CHARGE	Sat	Pasty
BURST REPORT IN END	Damp	crumbly

ITEM 5 – BOTTLE ROCKETS WITH WHISTLE

COMPONENT	WETTNESS	PHYSICAL CONDITION
OUTER PAPER	Sat	Soft
WHISTLE PYROTECHNIC	Wet	pasty
CLAY PLUG IN FRONT END	Damp	Soft
BURSTING CHARGE	Damp	crumbly
PLASTIC BODY	Wet	intact

ITEM 6 – SKY ROCKET

COMPONENT	WETTNESS	PHYSICAL CONDITION
OUTER PAPER	Sat	Soft
MAIN CHARGE	Sat	Pasty
CRACKLING BALLS ¼ INCH	Damp	Soft – will mash
PLUGS/CLAY	Wet	Soft to crumbly

Figure 12: Description of the dissected fireworks articles were recorded in the Dissection Log. A separate table was used for each week for each solution. Description of the external condition of the article and descriptions for each of the pyrotechnic components were recorded.

Dissection of the article was used to determine the physical condition of the article itself and the pyrotechnic components of the article. An example of a dissected 6-inch shell is shown in Figure 13. The examination looked at the condition of the paper shell, the lift charge, the burst charge in the center of the shell and the stars surrounding the burst. Each component was manipulated to determine if it was intact or if it would yield, mash or crumble under light to moderate finger pressure.

Figure 13: Shells were cut apart, contents examined and condition recorded. This 6-inch shell shows signs of crumbling stars after 3 weeks.

Task 2: Open Fire Burning

Two types of fires were used to burn the samples after soaking for a prescribed length of time. Small articles such as the Fountains, Bottle Rockets and Sky Rockets were burned on a propane burner fire. This was done so that the reaction of the article could be observed. These articles were so small that the flames of a wood pallet fire would obscure any reaction. The larger articles including the Firecracker bricks, Roman Candles, Cakes and Shells were burned on wood pallet fires. Later in the program, individual packets of firecrackers were also placed on propane fires to better see what reactions were taking place as the wood fire consistently obscured the reaction of this article. The remainder of the brick was still placed on the wood fire.

The propane burners were all fed from a common storage tank and individually controlled through a manifold with electric valves. Each burner could be controlled individually. The flame was adjusted to be equal on all burners using the burner unit adjustment. Articles were placed on expanded metal grates over the burners. One article was placed over each burner unit. Figure 14 shows a typical fire configuration. Observations of the fires showed that the reaction of the articles did not interfere with each other.

Figure 14: Typical burner arrangement showing an article over each burner (Sky Rocket on Left and Fountain on Right) for testing.

Figure 15 shows a typical wood fire. Two to four articles were typically placed on each pallet stack. Their locations were marked on a layout sheet that accompanies the test data.

Figure 15: A typical wood pallet stack fire showing three articles, the 500-gram Cake, Firecracker Brick and a 3 inch shell.

Task 2: Test Results

Test results were monitored and analyzed on the basis of the soak time required to achieve the following conditions:

- Maximum percent weight gain
- Specific levels of physical deterioration
- Specific levels of reaction

Correlations were then drawn between these parameters to define a range of soak times in each solution to achieve a minimum overall reaction of the individual articles.

Results: Maximum Percent Weight Gain

Articles from each solution were weighed upon extraction each week to determine the percent weight gain. This data was tabulated and the entire compilation is provided in Attachment 4.

Examples of the data analysis are provided below. Appendix B-5 from Attachment 4 gives the spread sheet used to compile and analyze the saturation data. The comparison made is based on the percent weight gain for each article. Two articles from each solution were extracted each week as described above. The weight gain for these two articles was averaged and is presented in the final tabulated data. The percent weight gain for a given article was then compared among the four solutions to get a picture of how fast each solution was able to saturate to a maximum weight gain for that article. Figure 16 shows the smaller items and Figure 17 shows the larger items comparing the weight gain for each of the four solutions.

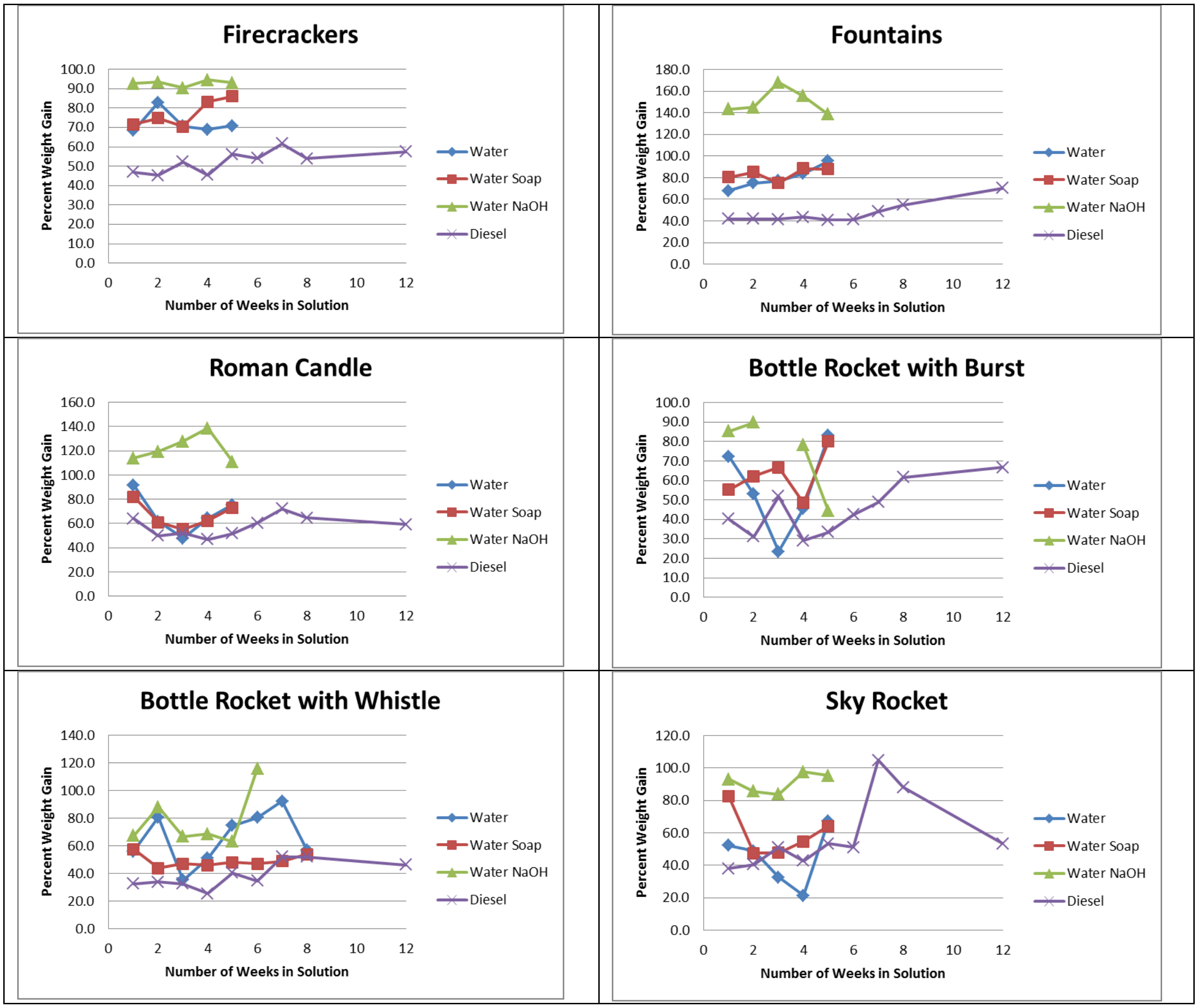


Figure 16: Percent weight gain of Small Fireworks Articles in four solutions

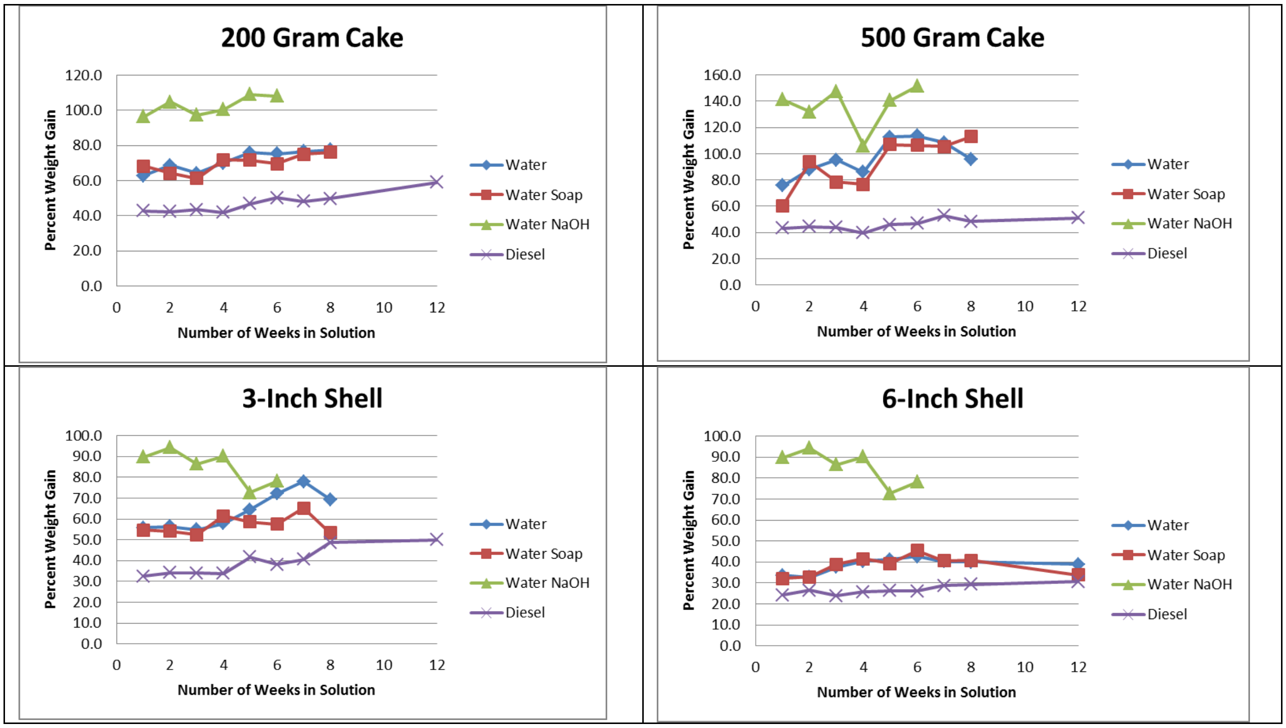


Figure 17: Percent Weight Gain of Larger Items compared in Four Solutions

Results: Weight Gain Conclusions:

Two observations stand out when examining this data. First is that the Water/NaOH solution is consistently the solution that provides the largest percent increase in weight. The second is that the majority of increase in any solution occurs in the first week with only small changes thereafter. Some articles actually show small decrease in weight gain over time, but this could be due to several factors including differences in draining time, loss of mass of paper due to deterioration in the soaking buckets and some loss of pyrotechnic as it dissolves in the solutions.

A ranking of percent increase would have Water/NaOH as the solution that creates the largest weight gain. Water and Water/Soap solutions are about the same with no significant difference between them. Diesel generates the least weight gain overall.

Results: Specific levels of physical deterioration

One of each article pulled for a given week's data was dissected and specific observations made as to the physical condition of the article and pyrotechnic within the article. Deterioration was observed on the exterior appearance of the article as shown in Figures 18 and 19. Figure 18 shows the deterioration of the 500-gram cake from week 1 to week 8 and the Fountain from week 1 to week 5 week in the Water/NaOH solution. Figure 19 shows the lack of apparent lack of deterioration of the 500-gram Cake in Diesel over an 8 week period. Since the appearance of the article has little measureable effect on the reaction or other sensitive parameter to the study, it was recorded for information purposes only. No analysis was performed. Each article was photographed to show this deterioration as an indicator of the effectiveness of the solution to attack the article.

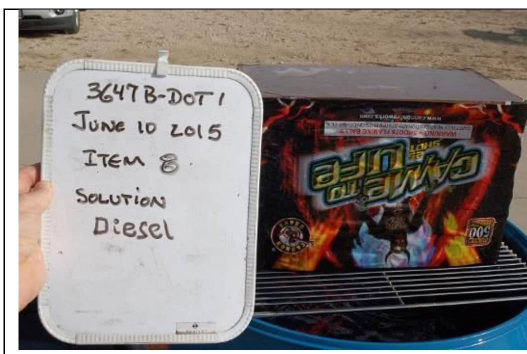
500 gram cake, caustic week 1

500 gram cake, caustic, week 8

Fountain, Water/NaOH week 1

Fountain, Water/NaOH week 5

Figure 18: Progressive deterioration of the physical condition of the articles was noted.



500-gram Cake, Diesel, Week 1

500-gram Cake, Diesel, Week 8

Figure 19: Diesel has the least effect of all solutions on the physical deterioration of the articles.

The primary focus of this investigation was on determining the effects of the solutions of the deterioration of the pyrotechnic materials in each article. The following tables present a summary of the deterioration results for all items. Included are results for various pyrotechnic components within each item. Various levels of deterioration have been assigned a numeric value to facilitate comparison among the different items and soaking solutions. The description of each level of deterioration and the numeric value are shown in Table 7. The level of 10 is assigned to the new article which has not been exposed to any soaking solution and represents the maximum physical integrity. A minimum of 1 is assigned to a component that has totally turned to liquid representing the minimum physical integrity. Table 8 presents the summary of the deterioration with the minimum level reached and the first week when that level was observed. In several cases, the description of a specific component in any given article could vary by one or more levels through the 12 week soak period. The time and level chosen for Table 7 represent the first observation of the minimum integrity. The changes in the observed deterioration may have been the result of a number of factors. (Most likely factors would be different formulations for stars used in different articles of the same type, such as red or blue stars, that are made with more or less binder which would affect the solution up-take rate.) Also noted was what appeared to be changes in the consistency of some powders likely caused by recrystallization of water soluble ingredients.)

Table 7: Definition of Levels of Deterioration

Numeric Level	Description of Pyrotechnic Composition
10	Dry – Hard, as new condition, Not exposed to any solution
9	Dry – Hard, exposed to solution but no apparent soaking
8	Damp or wet but star components are hard with no visible signs of deterioration
7	Wet, star components have crumbly outer layer with hard center
6	Wet, powder is clumpy or gritty but not pasty or liquefied
5	Wet, star components crumble to small pieces under finger pressure
4	Wet, star components crumble or mash to pasty texture under finger pressure. Also, may have slight gritty texture in the paste or may be described as “soft”.
3	Wet, saturated with pasty texture, few if any lumps or gritty (refers to both star and powder components)
2	Saturated, pasty and liquefied mixture. May have small gritty component or metallic particles.
1	Totally liquefied, may have a small gritty component or metallic particles

Examples of several types or levels of deterioration are shown in the following photos. The complete set of all photos for each of the articles for each solution and each week will be provided digitally.

Figure 20: Dry powder in Fountain, Level 10.

Figure 21: Dry stars and burst in 3-inch shell, Level 10.

Figure 22: Gritty powder after soaking in Diesel, Level 6

Figure 23: Wet but hard stars from 3-inch shell in diesel, Level 8.

Figure 24: Crumbly exterior with hard center from 6-inch shell in Water/Soap, Level 7.

Figure 25: Star from Roman Candle in Water/Soap, totally crumbly under finger pressure, Level 5.

Figure 26: Fountain powder from Water, totally saturated and pasty texture, Level 3

Figure 27: Sky Rocket powder liquefied in Water/NaOH solution, Level 1.

Table 8: Summary of Maximum Deterioration Reached (The lower the level, the greater the deterioration)

Solution:	Water		Water/Soap		Water/NaOH		Diesel	
Item/Component	Level	Week Reached	Level	Week Reached	Level	Week Reached	Level	Week Reached
Firecracker - powder	4	5	3	2	1	4	3	5
Fountain - powder	3	1	3	1	1	4	3	6
Roman Candle – Lift	2	2	3	1	1	4	5	3
Roman Candle – Stars	4	1	2	4	4	1	7	7
Roman Candle - crackers	3	1	3	1	2	2	3	2
Bottle Rocket w/Burst – Powder	2	5	3	1	1	2	3	1
Bottle Rocket w/Burst – burst charge	3	3	3	4	1	4	3	4
Bottle Rocket w/Whistle – Powder	3	1	3	1	2	1	3	1
Bottle Rocket w/Whistle - burst	3	4	3	4	3	3	3	4
Sky Rocket - Powder	3	1	3	1	1	1	3	7
Sky Rocket –	4	2	4	1	1	3	3	12

crackling balls								
200-Gram Cake – lift	3	3	3	3	2	2	5	7
200-Gram Cake – crackling balls	5	6	5	3	2	5	8	1
200-Gram Cake – Aerial Powder	3	2	2	1	1	6	3	1
200-Gram Cake – Aerial Stars	4	2	4	3	4	2	8	1
500-Gram Cake – Lift	3	3	3	1	1	2	6	7
500-Gram Cake – Crackling Balls	5	4	5	4	3	5	8	6
500-Gram Cake – Aerial Powder	3	3	1	7	1	5	1	7
500-Gram Cake – Aerial Stars	4	3	4	5	3	3	7	3
3-inch Shells – External Lift	1	4	1	3	1	2	4	3
3-inch Shells – Bursting Charge	3	8	3	7	2	2	3	12
3-inch Shells – Stars in Bursting Charge	8	1	7	6	1	5	8	1
3-inch Shells – Stars outside of Burst	8	1	8	2	2	4	8	1
6-inch Shells – External Lift	2	4	2	12	2	3	6	3
6-inch Shells – Bursting Charge	3	6	3	8	3	6	4	8
6-inch Shells – Small Stars in Burst	3	5	4	4	2	6	8	1
6-inch Shells – Small Stars outside of Burst	7	1	5	6	3	6	8	1
6-inch Shells – Large Stars	7	5	7	7	5	3	8	1

Based on all the results from Task 2 it was observed generally that when a component has reached a level of 4 or lower, it has lost sufficient physical integrity and soaked sufficient solution that it will likely no longer function as a nominal pyrotechnic material. At levels of 5 and 6 it may be marginally reactive and levels above 6 it may still have the ability to function with relatively vigorous intensity. As a result of this observation, a simple graphic or table can be constructed from Table 8 to show when the various solutions achieved a level of 4 or lower for a given component in an item. This is a bench mark condition indicating sufficient soak time to achieve the project goal of flammable solids comparable reactions. Individual results may vary among the articles in this study.

Also, some components in a firework item are more likely to cause significant reaction potential than others. Propelling charges, such as the powders in the bottle rockets and sky rockets would be more likely to be hazardous than the crackling balls in these same items. In like manner, the lift and burst charges in the shells would be the components that should be monitored as these are the propelling components in the shells. The stars, although potentially vigorous reacting, would be left at their origins without burst and lift reactions to propel them.

With these factors in mind, Table 9 has been constructed to indicate when an item's propulsive component reached a level of 4 or lower, indicating a deterioration to a significantly reduced reaction potential (i.e. flammable solids type behavior as opposed to a potentially class 1 behavior). This data should help identify the appropriate soaking times required to achieve a given level of potential reactive behavior based on deterioration of the propulsive components in the item. (Reactivity still remains the primary focus and will be discussed later.)

Table 9: Propulsive Component Deterioration to Level 4 or lower.

Solution:	Water		Water/Soap		Water/NaOH		Diesel	
Item/Component	Level	Week Reached	Level	Week Reached	Level	Week Reached	Level	Week Reached
Firecracker - powder	3	1	3	1	4	1	3	5
Fountain - powder	3	1	3	1	3	1	3	6
Roman Candle – Lift	4	1	3	1	4	1	NA*	NA
Bottle Rocket w/Burst – Powder	3	2	3	1	3	1	3	1
Bottle Rocket w/Whistle – Powder	3	1	3	1	2	1	4	3
Sky Rocket - Powder	3	1	3	1	1	1	3	7
200-Gram Cake – lift	4	2	4	1	2	2	NA	NA
200-Gram Cake – Aerial Powder	3	2	2	1	3	1	3	1
500-Gram Cake – Lift	4	1	3	1	4	1	NA	NA
500-Gram Cake – Aerial Powder	3	3	3	1	3	1	3	2
3-inch Shells – External Lift	4	1	2	1	3	1	4	3
3-inch Shells –	4	1	4	2	4	1	4	7

Bursting Charge								
6-inch Shells – External Lift	4	1	4	1	4	1	NA	NA
6-inch Shells – Bursting Charge	4	2	4	2	4	2	4	8

*NA = Deterioration Level of 4 or lower Not Achieved

Table 10 is constructed to indicate when a level of 4 or lower is achieved for the star components of the various items. This table compliments Table 9 in giving a more complete picture of the soak time required to reduce the physical integrity of the components to levels that will not likely support hazardous reaction characteristics.

Table 10: Star Component Deterioration to Level 4 or Lower

Solution:	Water		Water/Soap		Water/NaOH		Diesel	
Item/Component	Level	Week Reached	Level	Week Reached	Leve l	Week Reached	Level	Week Reached
Roman Candle – Stars	4	1	4	3	4	1	NA*	NA
200-Gram Cake – Aerial Stars	4	2	4	3	4	2	NA	NA
500-Gram Cake – Aerial Stars	4	3	4	5	3	3	NA	NA
3-inch Shells – Stars in Bursting Charge	NA	NA	NA	NA	3	2	NA	NA
3-inch Shells – Stars outside of Burst	NA	NA	NA	NA	3	2	NA	NA
6-inch Shells – Small Stars in Burst	3	5	4	4	4	4	NA	NA
6-inch Shells – Small Stars outside of Burst	NA	NA	NA	NA	4	4	NA	NA
6-inch Shells – Large Stars	NA	NA	NA	NA	NA	NA	NA	NA

*NA = Deterioration Level of 4 or Lower Not Achieved

Conclusions for Physical Deterioration versus Soaking Solutions

In summary for the propulsive components of the tested fireworks articles, most items in water based solutions will deteriorate to a level of 4 or lower within 1 to 2 weeks. The exception due to the excessive amount of paper is the 500-gram cake aerial charge taking about 3 weeks.

Diesel is significantly more variable often taking up to 7 to 8 weeks. For several items Diesel did not achieve a level of 4 or lower after 12 weeks. In short, there is no clear differentiation among the water based solutions for short term soaking of three weeks or less to achieve a level 4 or lower. Diesel on the other hand is much less effective in most situations.

For the stars in paper wrapped cakes the average soak time for water based solutions to achieve a level of 4 or lower is on the order of 3 to 4 weeks with little real differentiation among the solutions. For the shells, Water/NaOH was the only solution that consistently affected the stars to a level of 4 or lower with a minimum soak time of around 2 to 4 weeks required. The Water, Water/Soap and Diesel solutions were relatively ineffective at causing any change to the physical structure of the 3/8 inch and 1 inch stars in the shells. Most remained totally intact and hard through the entire 12 week trial.

Reaction Level Observations

The final observation and probably the most critical to the studies in the project is the specific level of reaction of the firework article as a function of soak time and solution. The project objective is to determine the best method to achieve a level of reaction comparable to that of a flammable solid, class 4.1 reaction. This would suggest a qualifying reaction is one that produces flame of less than 6-12 inches from the origin, no fiery projections beyond 1 foot and no explosive events.

Each type article was ignited in its new as-received condition over a fire and observed. The results serve as a baseline for all subsequent testing. Soaked articles as described above were subjected to either a propane burner fire or a wood pallet fire and reaction events recorded. Events of each reaction were recorded as accurately as possible. Some events were not observable or could not be precisely determined due to the flame and smoke interference. Events included the following:

- Time to first initiation or event
- Burst or explosive event
- Burn time of the article
- Burn time of any given component (star, powder)
- Throw distance of any particle or effect
- Flame or jetting size around the particle or effect

The reaction level observed was ranked based on criteria used to determine a transportation hazards classification. Table 11 gives a summary of the criteria used for each classification level or rank.

Table 11: Descriptions of Reaction Level for Fireworks Articles

Reaction Level	Description
Class 1.3	Flame jets or fireball in excess of witness screens (12-13 feet), significant fiery projections in excess of 50 feet, burst or explosive event with shock producing potential
Class 1.4 (other	Flame jets or Fireball in excess of 3 feet but less than witness screen, fiery

than S)	projections in excess of 3 feet but less than 50 feet, no significant explosive event.
Class 1.4S	Flame jets or fireball less than 3 feet, projections less than 3 feet, no explosive event, no events that would hinder first responder activity in immediate area.
Class 4.1	Flame or fireball less than 12 inches, projections less than 12 inches, no explosive events, flashes or pops of less than 1 sec are acceptable.

For an article to qualify for a flammable solids type reaction the events on the fire would include no bursting effect, no projections beyond 12 inches and no flame more than 12 inches from the article. There could be some crackling and popping noises from the small metallic particles in the articles and small flashes.

Since the articles must dry out in the fire to ignite, a time limit on when these reactions could occur was not imposed. The amount of paper, the weight gain and where they are in the fire can all affect this parameter. Also, with diesel, the soaking solution is ignitable and does contribute to the reaction of the article. This observation was noted. Observations with respect to the time it takes for a reaction to occur are brought into consideration as to the effects on a disposal method and will be discussed in the general conclusions section of this report.

A complete listing of the reaction times, levels of reaction and events recorded is presented in Attachment 6. Figure 28 shows Table 6-A from Attachment 6 which gives typical results from the Sky Rocket reaction behavior.

Table 6-A Sky Rocket (Item 6) in Water

lution	Water				
Week	Time to Initiation	Flame size (inches)	Projections (feet)	Approx. Burn Time (sec)	Probably Hazards Class
0	0:06	2-4	10+	3-4	1.4
1	2:47	1-2	1+	7	1.4
2	3:46	1	None		4.1
3	NDR*				
4	NDR				
5	NDR				
6	**				
7					
8					
12					
Dried Out					

*NDR indicates "No Detectable Reaction"
**Blank lines indicate no test data for that week; sample was pulled from rotation due to lack of reaction in previous weeks.

Figure 28 Table 6-A from Attachment 6 shows fire reaction data through week 6 for Sky Rocket Article in water.

Figure 29 shows Table 7-D for the 200-gram Cake results from Diesel soaking.

Table 7-D 200-gram Cake (Item 7) in Diesel

Solution	Diesel				
Week	Time to Initiation	Flame size (inches)	Projections (feet)	Approx. Burn Time	Probably Hazards Class
1	8:53	12-24	5-8	3	1.4
2	4:25	3-5	1-2		1.4S
3	4:40	1-4	2		1.4S
4	3:22	6-12	4-6		1.4
5	4:06	2-3	1-2		1.4S
6	2:32	4-6	2-4		1.4S
7	2:21	2-6	None		4.1
8	3:39	1-6	2-4		1.4S
12	4:00	6	2-8		1.4
Dried Out					

Figure 29: Fire reaction results for the 200-gram cake soaked in diesel from table 7-D in Attachment 6.

A summary of the test results from the fire reactivity observations is provided in Table 12. This table includes all articles for each solution and indicates the week in which the article reached a sustainable 4.1 classification reaction level. Some articles would fluxuate between 1.4 and 4.1 from week to week. This may have been due in part to the inability to observe some reaction events in the fire because of flame or smoke interference, or due to some other condition of the article itself. The week indicated in Table 12 is the first week of a sustained week to week classification of 4.1.

Table 12: Week at which Sustainable Class 4.1 Reaction was Reached

Item	Solution			
	Water	Water/Soap	Water/NaOH	Diesel
Firecracker	1	1	1	X*
Fountain	1	1	1	12
Roman Candle	1	1	1	1
Bottle Rocket w/Burst	1	1	1	X
Bottle Rocket w/Whistle	2	1	1	X
Sky Rocket	2	1	1	12
200-Gram Cake	1	1	1	X
500-Gram Cake	6	4	1	X
3-inch Shells – main	2	2	3	X
6-inch Shells – main	4	2	4	X

*X = indicates that sustainable 4.1 reaction level was not achieved

Examples of reactions observed and the classification recommended for the reactions are shown in the figures that follow.

6-inch Shell Dry – 200+foot projections Class

6-inch Shell Diesel at week 2, no projections

6-Inch Shell Diesel at 6 weeks

6-inch Shell Diesel at 12 weeks

Figure 30: Progression of reaction for 6-inch Shell in Diesel shows a significant change from dry to week 2 but no significant change from week 2 to week 12. Dry reaction is 1.3 and all soaked reactions are 1.4.

6-inch Shell in Water/NaOH at week 1

6-inch Shell in Water/NaOH at week 2

Figure 31: Progressive decrease in reactivity is quickly noted between weeks 1 and 2 in Water/NaOH moving from 1.4 to a 4.1 reaction level.

500-g cake in Diesel week 3 | 500-g cake in Water/Soap week 3

Figure 32: Comparison of events from 500-gram Cake at week 3 in Diesel and Water/Soap show both still throw projections over 3 feet, but Diesel reaction is much larger.

Data show that in the water based solutions, most articles achieved a Class 4.1 reaction level in one to two weeks. One exception is the 500-gram cake probably due to the amount of cardboard wrappings around the pyrotechnic materials making it take longer to thoroughly saturate the pyrotechnic. The other is the shells due to the hard case that proved to limit the amount of solution that could be absorbed. Diesel on the other hand achieved a 4.1 level of reaction only for the Fountains and Sky Rocket at 12 weeks. All other articles remained in the Class 1 reaction behavior classification through the 12 week period due to flame/fireball size or projections.

Dried Articles:

In a side study, 500-gram cakes and 3 inch shells soaked in the three water based solutions for 8 weeks were removed from their respective solutions and dried in the open air for 3 weeks. Drying was during the month of August with maximum day time temperatures reaching 90 °F. They were then placed on a wood pallet fire to determine if they would return to a more reactive state. Data indicate that the 3-inch shells returned to a 1.4 class reaction level. The water soaked 500-gram cake was near a 1.4 level and the Water/NaOH and Water/Soap soaked cakes remained at a 4.1 level showing no reactions at all. The following figures demonstrate these results.

3-inch shell Water/NaOH Week 3 | 3-inch shell Water/NaOH Dried

Figure 33: The Water/NaOH soaked 3-inch shell showed only smoke reaction at 3-week soak but returned to a 1.4 class reaction with significant fireball when dried.

3-inch Shell in water 3 weeks shows only smoke

3-inch Shell after dried out with projections.

Figure 34: The water soaked 3-inch shell showed similar results with fireball and projections after a 3-week drying period, returning to a 1.4 class reaction.

500-g cake Water week 3 with small flame

500-g Cake, Water, Dried 3 weeks with flame

Figure 35: The 500-g Cake from Water after drying 3 weeks shows some tendency to Class 1.4 with 12 inch flame, similar to same article after 3 weeks soaking in Water which showed flame and some projection throw.

Results from the drying of pyrotechnic articles after significant soak times of up to 8 weeks indicates that if dried sufficiently, they will return to a 1.4 type reaction. It is unlikely that they would return to the original level of reaction of a new dry article simply because of the way the water attacks the chemicals in the pyrotechnic. Chemicals that can dissolve in water would be recrystallized in the dried material changing the physical structure of the pyrotechnic. Complete and rapid consumption of the pyrotechnic depends heavily on the physical distribution and particle sizes of the constituents. Recrystallization will likely change the particle sizes of the oxidizer or fuel constituents resulting in a larger and less well distributed mix causing the pyrotechnic to not perform as when new.

Summary from Task 2

Saturation:

- Saturation was maximum with the Water/NaOH solution

- Saturation was near equivalent with either the Water/Soap or plain Water but slightly less than the Water/NaOH solution
- Saturation was minimum for Diesel
- All solutions saturated to a level of 40% or greater of the initial weight of the firework
- Saturation to near maximum for a given solution occurred within the first week. Minimal additional saturation occurred in subsequent weeks.

Physical changes:

- Physical deterioration was most complete with Water/NaOH
- Physical deterioration was similar for water/soap and plain water, but Water/Soap was slightly more effective on the stars or pressed pellets
- Diesel was least effective and showed little or no physical change on stars, pressed pellets and packaging.

Reactivity:

- Reactivity to a class 4.1 was achieved effectively in all water based solutions with little difference in time to achieve that level of reactivity
  - Reactivity to Class 4.1 took 1-3 weeks for smaller items with minimal paper wrappings
  - Reactivity to Class 4.1 took 3-6 weeks for larger items with significant paper wrappings
  - Reactivity to Class 4.1 took 2-4 weeks for aerial shells
- Reactivity to Class 4.1 was not achieved in Diesel except for two small items.
  - Reactivity to Class 4.1 was only achieved at 12 weeks for the fountain and sky rocket
  - Reactivity to Class 4.1 may have been achieved for the Roman candle also
  - Minimum reactivity (but still Class 1.4 or 1.4S) took between 2-3 weeks for all other articles.

Time to Reaction:

- Time to reaction in a fire was significantly longer with Water/NaOH solution than in either of the Water or Water/Soap solutions often taking 60 to 120 minutes for the 200-g and 500-g cakes to react.
- Water and Water/Soap solutions delayed reaction more than Diesel but less than Water/NaOH. Typical initiation in Water and Water/Soap for the 500-g cakes was 45 minutes.
- Diesel reactions typically took less than 15 minutes with many reaction occurring within 5 minutes.

Safety and Health Hazard Concerns:

- Water or Water/Soap solutions present no significant hazard or health concerns in and of themselves.
- Water/NaOH presents a caustic hazard even in a 5% solution. Contact with this solution could cause skin irritation. Splashes which are a definite possibility when loading larger fireworks articles could cause eye irritation. It also presents a chemical hazard when finally removed for destruction.

- Diesel is a Class 3 flammable liquid and must be handled as such.

Destruction of Desensitized Fireworks:

- Destruction is typically by fire
- All water based solutions will cause a significant impact on the ability to burn the soaked fireworks
- Water/NaOH will cause the most significant impact due to the increase in solution uptake and possible interaction of the NaOH with the paper that appeared to actually act as a fire retardant during the Task 2 testing.
- Diesel is a fuel that quickly becomes involved and aids in burning out the fireworks. Although the fireworks were not effectively reduced in reactivity to a 4.1 class, they were significantly subdued from nominal behavior to at least a 1.4 and in some cases a 1.4S level of behavior.

Based on the results of Task 2 it appears that reaction levels comparable to a Class 4.1 Flammable Solid can be achieved in all water based solutions tested. The timing of when the articles reach this level depends more on the physical construction of the article than on the type of solution used for soaking. Smaller articles will achieve the level in 1-2 weeks. Plastic encased articles will be slightly longer. Large items such as the 500-gram cakes take up to 6 weeks to totally resolve to a 4.1 reaction level. Articles with hard outer casings, such as the aerial shells, will take longer because the shell inhibits the saturation process. Within one to two weeks of each other, all water based solutions resulted in a 4.1 reaction level.

The total amount of weight gain during the soaking process does not appear to have a significant effect. The most significant gain was in the first week with only small weight gain after that. Regardless, within the range of 40-100% weight gain, a level of 4.1 was achieved in water based solutions.

Physical deterioration was also not a significant factor in determining the overall reaction level in the water based solutions. Stars in the Roman Candle, 3-inch and 6-inch shells showed different levels of physical integrity from hard to soft depending on the soaking solution, but all reached a 4.1 level of behavior after a soak time of a few weeks.

Diesel was the exception. Diesel had the least effect on the physical condition of the fireworks articles, both from the stand point of the exterior of the article as well as the pyrotechnic components. Although powders were saturated with diesel, they were not significantly changed. Stars or other pressed components remained intact and hard through 8 weeks. A small change was noted on some stars in week 12 but this was minor compared to the effects of Water/Soap and Water/NaOH. Even the colors on the paper wrappings remained almost unchanged in most cases. The most significant change to the articles from the diesel resulted due to saturation of the powdered components. The effect was to slow down the flame spread through these powders and significantly limit the burst or deflagration potential. Thus, projection or explosive events were significantly reduced or stopped. Although a reaction level of 4.1 was not achieved in diesel, the overall reactions were reduced. It is suspected that this is because the powder components of the articles was saturated and could not burn as efficiently as when dry, thus they did not produce the propelling effect of a deflagration burn.

It is concluded from this study that a batch process for soaking fireworks articles can be developed to safely reduce reaction levels to that of a flammable solid 4.1 behavior. This would require a water based solution. Articles would best be segregated into two descriptions:

- One – small to medium paper wrapped articles such as bottle rockets, fountains, sky rockets and cakes up to 200-grams. These should be soaked for 1-3 weeks.
- Two – large articles such as cakes over 200-grams and all hard cased articles such as aerial 3-inch and larger shells. These should be soaked for 4-6 weeks to achieve the 4.1 behavior.

Diesel soaking will not achieve a 4.1 level of reaction in 12 weeks, and will not likely achieve that level for any duration of soaking. The maximum achievable level is Class 1.4 for larger articles such as the aerial shells, and 1.4S for small articles such as Fountains and Sky Rockets

Task 3 Batch Process Pilot Unit Design

Task 3 requires the design and construction of an operational batch process unit capable of desensitizing fireworks to a level of reactivity that can be designated as UN3380, Desensitized explosive, 4.1. The statement of work, copied below, describes these requirements:

> *3. Task 3: After the "proof of concept" work has been completed, the contractor must design and build a small pilot unit capable of desensitizing batches of 1.3G and 1.4G fireworks articles safely to render them effectively harmless for transport and disposal. The pilot demonstration unit should be entirely constructed of non-sparking, static resistant materials and must subject the fireworks articles to no electrostatic friction or shock, impact violent deformation of the outer shell casings.*
>
> *Deliverable 3: A Preliminary Test Plan consisting of the final design of the fireworks desensitizing pilot unit with engineering drawings of construction. The Preliminary Test Plan will address the safety of fireworks during transport, storage, handling, and disposal as well as any other method of handling performed on site. In addition, the contractor must submit a statement to the PHSMA agreeing that all process technology design and engineering drawings funded by this award will be freely available to the United States Government and all other interested parties.*

Selection of the batch process unit design is based on the success of the Task 2 results which used readily available plastic drums of various sizes to contain the soaking solution and fireworks articles. No special tools or implements were required. Minor modifications were made to the drum lid for safety concerns as will be identified. Compliance to the requirements can be met with few exceptions and these exceptions are addressed in the hazards analysis and procedure for use of the batch process unit.

Batch Process Unit:

The batch process unit is a plastic drum with a removable lid that has a sealing gasket. The size of the drum is set by the quantity and sizes of the fireworks articles that will be contained in it. SMS used 5-gallon pails, 30-gallon and 57-gallon drums for Task 2 efforts. All of these were completely adequate for the processes involved. It is not recommended that the size of the drum be in excess of 57-gallons for handling purposes.

Materials of construction varied slightly but were all basic polyethylene, HDPE or similar materials meeting 1H2 drum description and requirements. The drums and pails have removable lids with gaskets. The 5-gallon pails had snap-on type lids with rubber gaskets. The 30-gallon drums had plastic bands around the lids to secure them and the 57-gallon drums had a metal retaining band on the lid to secure it. Both types of drum lids also had gaskets.

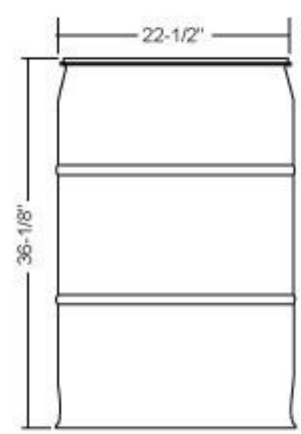
Example drums may be viewed at the following web locations. These are examples and not inclusive to all suppliers of drums and pails. SMS is not recommending any specific supplier. On-line suppliers as well as local providers may be used.

S-11861, Blue, Open, 30-gal, 1H2/Y180/S from Uline
S-9945, Blue, Open, 55-gal, 1H2/Y250/S from Uline
www.uline.com /plastic-drums

Typical drums with basic dimensions given from the Carycompany (http://www.thecarycompany.com/containers/drums.html) are shown below. These are straight sided 57-gallon and 30-gallon drums with a metal band clamp on the lid. The 57-gallon drum was used by SMS in Task 2 efforts and will work for the batch processing of a large quantity of fireworks or fireworks of larger size such as the 500 gram cakes. Similar drums from various vendors can be used.

57 GALLON STRAIGHT-SIDED
OPEN HEAD PLASTIC DRUM

PART#:	56W54B (Blue) Drum with Lever Lock Ring and 2"&3/4" Fittings
UN RATING:	UN 1H2/Y250/S
CAPACITY:	55 gallons / 217 Liters (57 gal overflow)
COLOR:	Blue
RING:	Lever Lock
DRUM HEIGHT:	36-1/8" (917 mm)
DIAMETER:	22-1/2" (572 mm)
MATERIAL:	High Density Polyethylene
MIN. WALL THICKNESS:	0.087" (2.2 mm)



	NOMINAL TARE WEIGHT: 24.9 lbs. (11.3 kg)

Figure 36: Typical 57-gallon plastic drum as used for conditioning/soaking of fireworks.

A 30 gallon straight sided drum from the same vendor is shown below. The exact drum was not used by SMS. The drum used by SMS had a nylon strap to secure the lid which worked adequately. However, that drum had a gasket that was not integrated into the lid as were the gaskets on the pails and 57-gallon drum. As a result the gasket was very difficult to secure and keep in place when trying close the drum. It is suggested that a drum with a gasket attached to the lid be used to minimize problems with closing the drum.

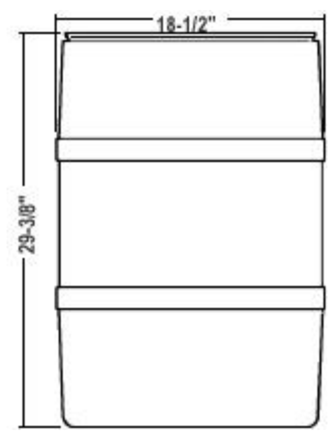
30 GALLON STRAIGHT SIDED OPEN HEAD PLASTIC DRUM		
	**PART#:** 56W30B (Plain) & 56W31B (w/ Fittings) **UN RATING:** UN 1H2/Y180/S **CAPACITY:** 30 gallons (114 liters) **COLOR:** Blue **HEIGHT:** 29-3/8" **DIAMETER:** 18-1/2" **MATERIAL:** High Density Polyethylene **NOMINAL TARE WEIGHT:** 15.5 lbs **FOB:** Addison, IL	

Figure 37 The 30-gallon drum was used for intermediate sized or quantities of fireworks.

6 Gallon White Bucket

Specifications

Item # 2389	**Weight in pounds** 2.4
Availability In Stock. Ships Soon.	**Manufacturer** Letica®
Sold By Each	**Manufacturer Part #** 6R WH00
Catalog Page Number P-153	

Product Description

11-3/4" Top OD, 16-3/4" Height and 10-1/4" Bottom OD.

Figure 38 The 5- or 6-gallon containers have the following description:
http://www.usplastic.com/catalog/item.aspx?itemid=33033&catid=752

Typically the lid for the 5 and 6-gallon pails is sold separately. Verify the presence of a gasket in the lid that is secured to the lid. Any of these or similar products offered by any number of vendors would be acceptable for use in the batch process.

The critical features for the container are these:

Good quality construction,
Containers should be 1H2 rated with fully removable lids
Lid with gasket and positive means of attachment
(Snap on style for small containers)
(Band clamp, plastic or metal, for larger containers)
Gaskets attached to the lid (preferred)

Metal containers are not recommended for this application. Studies and testing as witnessed by SMS have shown that metal containers have the potential to house the fireworks until substantially dried out and may contribute to the confinement of the materials as they ignite. Metal containment could lead to increased reactivity of the batch materials in a fire.

Safety Concerns and Compliance with Task Requirements:

The description of the batch process unit included the following requirements

The pilot demonstration unit should be entirely constructed of non-sparking, static resistant materials and must subject the fireworks articles to no electrostatic friction or shock, impact violent deformation of the outer shell casings.

Compliance to these requirements is achieved as follows:

The construction of the containers and drums is polyethylene with the exception of the handle on the 6-gallon pail (if present) and the metal lid band on the 30- and 57-gallon drum. The Hazards Analysis (SMS-3647B HA) addresses these concerns with the following conclusions:

- The metal bail on the 6-gallon pail is light weight and attached to the container in such a manner that it poses little if any safety hazard to the loading or unloading of fireworks into the container. Procedures should specify that the bail is in a fully down position during the loading process and that the container is first filled to approximately 1/3 capacity with soaking solution before adding any fireworks.

- The metal lid clamp on the 57-gallon and 30-gallon drums represents a minimal hazard to the fireworks as they are loaded or unloaded. The lid and metal band should be placed in a safe location, away from the drum during loading operations to prevent them from contacting the fireworks as they are loaded. The drums should be filled to about 1/3 capacity with soaking solution before fireworks are added. Removal or installation of the band after the fireworks have been added to the soaking solution poses no safety hazard since the fireworks are wetted and immediately desensitized to some degree upon loading. After soaking the recommended time, the fireworks are sufficiently desensitized as to render them non-reactive.

- Electrostatic charge on polyethylene drums is likely present when the drums are empty. The charge is slowly dissipated over time and is slow to dissipate when given a path for discharge. Sparking from the drum is unlikely. Drums and pails should be filled with soaking solution before adding any fireworks articles. Adding soaking solution will aid in discharging any static charge on the drum and will significantly reduce the potential for discharge of electrostatic charge from the interior of the drum to the articles. Personnel loading the fireworks should wear non-static clothing, such as cotton. Synthetics and polyester fabrics should be avoided or at minimum covered during the loading operation.

- Compliance to the shock and friction requirements is inherently met as the plastic materials of the drums and containers provide no means for friction or impact.

- Compliance to the elimination of any significant physical damage or deformation to the articles is met as nothing need be done to the articles before they are put into the soaking solution.

One small alteration is recommended for all containers. Due to the possibility of some off-gassing of pyrotechnic materials in the presence of water and to allow for escape of any trapped air, a small hole should be drilled into the lid of the container. An 1/8 inch (0.125 inch) diameter hole as drilled in the top of each lid. The observed result was that no accumulation of gasses built up in the containers. This was effective in venting all gasses and pressure caused by temperature changes. SMS did not notice any significant decrease in liquid level over the 12 week process in any of the four soaking solutions used. Items were stored outdoors, fully exposed to the sun during the summer months of June, July and August.

Batch Process Test Plan

Selection of the batch process took into consideration the summarized findings from Task 2. The water based solutions were most effective in reducing reactivity to a Class 4.1 level. None of the water based solutions stood out remarkably in reducing the level of reactivity to the required level with respect to time of soaking to achieve that level. Different solutions did perform differently on individual parameters, but the final reactivity results did not discriminate among them with any significant benefit.

Water only was selected as the simplest solution to prepare. Water/Soap and Water only solutions performed with equivalent results. Based on the fact that Water/NaOH presents both a safety and health hazard, besides extending the burn-out time for destruction, it was eliminated from consideration in the final batch process review.

The Diesel solution was also selected as it presents a desensitizing solution that will significantly reduce the reactivity of a firework but will also allow the desensitized fireworks to be consumed readily in a fire. The question to be answered by including diesel in the study is to see if there is a mass effect which will boost the reactivity, pushing the hazard beyond a point that would be acceptable for handling, shipping and destruction.

The following matrix was implemented:

Drum configuration: 57-gallon drum with removable lid.

Test: External Fire using wood pallets with one drum on fire.

1. Drum A: Water only solution
   Soak time 4 weeks
2. Drum B: Diesel solution
   Soak time 4 weeks
3. Drum C: Dry Fireworks Baseline without 3” and 6” Shells
4. Drum D: Dry Fireworks Baseline 3” and 6” Shells only

Batch Process Unit Preparation:

Preparation of the batch process unit.

1. Purchase a suitable container, or containers of the proper material as described above. Depending on the amount of fireworks to be processed, and the sizes of the articles, the unit may be anywhere from 5 gallons to 57 gallons. Sizes larger than 57-gallons are not recommended due to handling issues.
2. Place the unit in a suitable location, isolated from the majority of traffic in the area, to minimize contact with personnel and equipment movement.
3. Place the unit in a spill containment pan if required by code. Spill containment should be slightly greater than the capacity of the process unit (recommended at 125% of the volume of the processing unit(s) in the spill container).
4. Drill a 0.125 inch hole in the lid.
5. Fill the container 1/3 to ½ full of the soaking solution.
6. Place the fireworks into the solution.
7. Submerge the fireworks by pushing them into the solution
8. Top off the container with additional soaking solution to assure all fireworks will be submerged when saturated.
9. Place the lid on the unit and secure it by snapping on or with the band clamp.
10. Mark the container to identify what soaking solution it contains and that it contains fireworks.
11. Mark the container with the most recent date that any fireworks were added.

Preparation of the fireworks.

1. Remove or cut open Bubble packs, plastic wraps and tight fitting or waterproof packagings. (Total removal may not be necessary if the package can be breached to allow soaking solution to freely enter the package and contact the fireworks articles.)
2. Place the fireworks into the solution in the container
3. Assure that there is sufficient solution to cover completely all fireworks articles. (Initially, the fireworks will tend to float but will gradually soak and sink. Push the fireworks into the solution to completely submerge them to make sure there is sufficient solution in the container.)

Task 4: Testing of Batch Process Units

Safety and hazards concerns for the batch process were reviewed against the Hazards Analysis (Attachment 1) to verify that all aspects of this process were covered by the analysis. It was determined that there were no additional safety concerns posed in the batch process that were not covered. A procedure was written to cover the operations associated with the batch process. This procedure, SMS-3647D-TM Rev 0, is included as Attachment 7.

Loading Batch Process Drums

Drums were loaded with fireworks according to the test plan developed in Task 3 and operating procedure for Batch Process Testing. Table 13 shows the quantity of each type of fireworks article that was placed in the batch process drums. Approximately the same number of each article was placed in each drum.

For safety purposes, the 3-inch and 6-inch shells were not placed with the rest of the small fireworks for the dry baseline testing. The concern was having the mixture of the shells with the smaller articles for storage and for testing that if a large shell were to explode early in the burn, it would scatter the smaller articles about the test area without allowing them to function in a bulk situation. Thus a separate drum was used for the dry baseline shells.

Table 13: Quantities of Fireworks Articles in Batch Process Drums

Article	Diesel	Water	Dry – small	Dry – Shells
1 – Fireworks	3 bricks	3 bricks	3 bricks	None
2 - Cylindrical Fountains	25	25	25	None
3 - Roman Candles	25	25	25	None
4 - Bottle Rockets	43 each 12 packs	43 each 12 packs	48 each 12 packs	None
5 – Whistle Rockets	24 each 12 packs	24 each 12 packs	24 each 12 packs	None
6 – Sky Rockets	10 each 12 packs	10 each 12 packs	10 each 12 packs	None
7 – 200 g Cakes	6	6	6	None
8 – 500 g Cakes	3	3	3	None
9 – 3-inch Shells	12	6	None	16
10 – 6-inch Shells	3	3	None	2

The average total weights of the articles were obtained during the Task 2 preliminary evaluation testing. These weights and the gross total weight per drum for each article are listed in Table 14. Note that the gross weight is the weight of the article. No specific calculation was made to determine the approximate pyrotechnic weight of the article.

Table 14: Approximate Gross Weight of All Materials in Batch Process Drums.

Article	Article Weight (grams)	Total in Diesel	Total in Water	Total in dry small	Total in dry Shells
1 – Fireworks	1299*	3897	3897	3897	
2 - Cylindrical Fountains, each	82.3	2057	2057	2057	
3 - Roman Candles	137	3425	3425	3425	
4 - Bottle Rockets	15.5**	667	667	667	
5 – Whistle Rockets	26.2**	629	629	629	
6 – Sky Rockets	21.0	2520	2520	2520	
7 – 200 g	1004	6024	6024	6024	

Cakes					
8 – 500 g Cakes	4004	12012	12012	12012	
9 – 3-inch Shells	193	2316	1158		3088
10 – 6-inch Shells	1568	4704	4704		3136
Total Gross Weight of Articles (grams)		**38,251**	**37,093**	**31,231**	**6224**

*Firecracker Brick
**Weight of 12 pack.

Sample Preparation and drum loading

Sample preparation was done by making sure all fireworks articles were basically intact and in reasonably good condition. This meant that none of the articles were damaged to the point that they were leaking pyrotechnic materials from the packaging or the article. Packages on the packaged articles were breached by cutting the outer wrappings to allow the soaking solution to get in contact with the articles. Plastic wrappings around the cakes were torn, cut or partially removed. Plastic bags containing articles were cut open or removed.

Figures 39 and 40 show examples of the fireworks as received. Figures 41, 42 and 43 show various stages of the fireworks as they were loaded into the drums.

Figure 39: Typical Fireworks articles as received in vendor/manufacturer's packaging

Figure 40: 3-inch shells as received in vendor packaging.

Figure 41: Bottom layer with shells and large cakes. Order of loading was not specific. Materials were placed to take up space.

Figure 42: Additional packaged and unpackaged articles added to container.

Figure 43: Full container ready for addition of soaking solution.

Figure 44: Full containers were photographed and documented.

Batch Process Loading Time

Batch process loading times would average about 2-3 hours per drum with two people working. This includes time to open or unbox the fireworks, open or cut packaging to allow for penetration of the soaking solution, and documenting the contents. Given an operation where documentation was not needed, the time would be slightly faster. Gross weight of the contents of the drums was on the order of 37-38 kg (84-86 pounds).

Testing:

Samples were placed in the drums on December 9, 2015. Water and Diesel were added to the drums on December 16, 2015. Testing was performed at the 4 week soak time on January 13, 2016. The baseline dry fireworks were tested on January 19, 2016.

Each drum was tested individually on a wood stack fire. Figure 45 shows a typical stacking arrangement for the fires. This consisted of a center stack of wooden shipping pallets with one or two pallets stacked vertically to the each side of the center stack. These vertical pallets served to help contain the fireworks articles from rolling off the side of the center stack and helped to keep them in the fire.

Figure 45: Fire stack arrangement typical for the batch process tests.

Paper and kerosene or diesel was used as accelerant for initiation of the fire to assure a good ignition of the wood. Two bag igniters were used to initiate the fire, fired remotely from the control bunker. Photo and video documentation were provided.

Task 5: Results and Analysis

Test Results:

A summary of the test results is given in Table 15 indicating the times to various reactions, total time to consume the articles and maximum event criteria such as throw distance and flame jetting.

Table 15: Test Results from Batch Process Testing

Event	**Dry Shells**	**Dry Small Articles**	**Diesel Soaked**	**Water Soaked**	**Comments**
Ignition of wood	0:0	0:0	0:0	0:0	
Engulfing of drum	1:40	1:21	0.25	1:43	Point at which fire has surrounded the drum
Breaching of drum			4:07	3:42	
First Reaction	4:40	3:03	4:19	4:30 (smoke) 12:22 (Sparks)	First event associated with ignition of a fireworks article

Maximum Throw of fiery particles	200 Ft	150-200ft	15-20 ft	6-10 ft, small sparks	Stars, large particles, parts of an article such as the aerial effects from a cake
Maximum flame jetting	6-10 ft	3-6 ft	6 ft	6 ft	Flame jetting without particle throw
Time of Last Event	4:50	4:41	25:30	About 120 minutes	
Duration of events	0:10	1:38	21:11	About 120 minutes	

Baseline Dry Test:

The baseline dry tests showed how reactive and violent the event can be from a drum full of fireworks. Consumption of the fireworks was very quick, lasting only 98 seconds for the small articles and about 10 seconds for the shells. Once the flame penetrates the drum, all fuzes will ignite quickly. Aerial effects from the cakes were expelled up to 200 feet from the fire. It was not possible to see how far the bottle rockets and sky rockets went, but it is assumed that their flight distance was for a typical article properly launched and would be within the 200 foot limit of the cakes.

There were no mass explosions observed. It appeared that all articles were individually ignited, although there were many simultaneous ignitions of various articles. No unconsumed articles were found outside the fire. It appeared that everything was ignited in the fire. The following figures show typical and/or maximum events from the baseline fires.

Figure 46: Baseline dry shells event with 6 inch shell. Dark object above screens is the drum that was blown up into the air.

Figure 47: Baseline dry small fireworks event shows areal burst (red stars) in upper center of frame.

Figure 48: Exploding aerial effect from 500 g cake near camera at 150 feet from fire.

Diesel Soak Test:

The Diesel soaked items started to ignite about 41/2 minutes into the fire, just after the drum ruptured or melted through. Numerous small events were observed over the next 21 minutes. One or two significant events were observed where ejection of materials from article ignitions extended up to 20 feet from the fire. Large shells expelled materials up to 15 feet from the fire. The Cakes seemed to expel materials the farthest from the fire. No mass explosions were observed. Flames from the burning diesel lifted about 12 feet into the air. Articles continued to ignite for about 21 minutes after the first event. No significant flame jetting was observed. Flames were typically less than 4 feet from the source.

Figure 49: Maximum event from Diesel fire throws effects about 15 feet.

Water Soak Tests:

Water soaked materials began to ignite about 4 ½ minutes into the fire with a small whiff of smoke, typical of a wet article smoldering. This may have been water spilling from the drum as it burned through rather than a fireworks article. The initial events definitely attributable to fireworks initiations were observed about 12 minutes into the fire with some of the articles igniting and spraying small sparks about. Most materials produced only smoke with very little ignition early in the burn. As the burn continued the events became more significant with one shell producing a 4-6 foot flame about 32 minutes into the burn. Numerous small events with sparks and expelled materials up to 12 feet were observed after 20 minutes and continued for over two hours. Most sparks were of little consequence from a hazards standpoint. They were small and burned out quickly in the air. Numerous crackling and popping events were observed over the duration of the fire as the cakes would dry out and ignite the pyrotechnic in them. Individual tubes would burn off with little or no consequences having flame less than 6 inches and not throwing sparks or fiery embers more than one foot.

The 6 inch shell appeared to be the only article with a significant event from the water soaked articles. One of the 6-inch shells in the fire produced a flame about 6 feet above the source that lasted for about 10 seconds. Figure 50 shows the maximum point of reaction from this event.

Figure 50: Maximum event from water soaked fireworks shows that drying will allow materials to burn.

Batch Process Analysis and Conclusions:

Batch processing to desensitize fireworks can be accomplished efficiently by using containers with a soaking solution to saturate the articles. Containers can be sized to fit the requirements of an operation based on the quantity of articles and sizes of articles that need to be processed. SMS has used 5 gallon pails, 30 and 55 gallon drums to effectively saturate fireworks articles. The process is simple, requires no expensive or sophisticated hardware and can be effectively implemented by anyone.

Processing Time

Based on the loading of a limited number of 55 gallon drums for the Task 4 Batch Process effort, a through put loading time of approximately 2-3 hours per drum for two people working is required. This time allows for the fireworks to be removed from their original packaging, boxes or containers. It allows for time to open or cut wrappings on the packages to allow for penetration of the soaking solution and placement into the drum. The drums are then filled with the soaking solution and placed in a retention area for the required soak time. Shorter times for loading could result from a production oriented process where there is a significant quantity of articles to be processed.

For general mixed content, about 38 kg (85 pounds) of gross weight fireworks articles can be held in a single 55 gallon drum. More or less than this amount may be possible depending on the configuration of the articles placed in the drum. Packing density will depend highly on the shape and sizes of the articles and whether or not there are a number of different sized articles that can be placed in a drum.

Test Results

Results from the batch process testing showed that the Diesel soaked articles behaved as was observed in the Task 2 exploratory testing with a typical Class 1.4 type behavior as the maximum event. Materials were thrown up to 20-30 feet from the fire. No mass explosions or propagation events occurred. Consumption of all materials took just under 30 minutes.

The water soaked testing showed less reaction overall than the Diesel soaked articles as was expected. Generally the results would be considered as a class 4.1 behavior as flames and sparks for the articles were expelled or thrown less than 3 feet. However, as the test proceeded and the fireworks articles dried out, the reactions became stronger and more significant. Some reactions were observed to throw sparks several feet. These were usually small reactions that would not significantly hinder first responder personnel.

One event, likely from a 6 inch shell, had a flame of about 6 feet that lasted for about 10 seconds. This would be a definite 1.4 type reaction. In all, no mass reactions or propagation events occurred. Events continued for at least 120 minutes.

Conclusions for Batch Process Testing

Based on these results SMS concludes that as determined in the preliminary testing, small fireworks can be rendered to a class 4.1 type behavior when soaked for a period of time in water or water based solutions. The type of fireworks that can be rendered to this classification include all with light paper exterior wrappings, exteriors with light cardboard, fireworks that have permeable caps, or caps that can be softened with water. Articles that are wrapped with a large thickness of paper or light cardboard such as the multi-shot cakes are more difficult to render to a 4.1 classification. Longer soaking times are required for these articles.

It was also observed that if dried out, more significant reaction events will occur. These events will typically be significantly less than a dry unaltered firework of the same type, but can approach a class 1.4 behavior. In particular, this will occur with the larger fireworks with stars and pellet, such as the aerial shells. Drying can occur if the articles are removed from the soaking solution, or if exposed to fire and hot embers for a long period of time.

Final Recommendation

SMS recommends the following:

Diesel soaked items will likely retain a class 1.4 hazards definition based on the throw distance of fiery embers and size of flames. All items will be in this class definition.

Water soaked items can be segregated into small paper wrapped articles that can be rendered to a Flammable Solids 4.1 classification. Larger items in particular aerial shells should retain a class 1.4 hazard definition.

Batch process handling of fireworks can be easily accomplished using plastic or HPDE pails and or drums with removable lids, constructed to 1H2 standards. Size of container will depend on the quantity and size of fireworks needing to be processed. Up to 100 lbs of dry unwrapped fireworks can be placed in a 55 or 57-gallon drum. Loading of drums can be accomplished in about 1 to 2 hours depending on total preparation needed, such as removal from packaging and breaking open wrapped containers that would prevent soaking solution from reaching the articles.

Use of larger drums is not recommended.

Use of metal containers is not recommended.

Water-based soaking solutions are most effective in desensitizing the fireworks to a UN3380, Desensitized, explosive 4.1 hazards classification. Addition of surfactant is minimally effective in speeding up processing time.

Use of chemical additives to the water such as Sodium hydroxide (NaOH) may improve total desensitization but creates a more difficult material to handle both from the ability to burn it in a fire and from a chemically hazardous material.

Diesel is an excellent desensitization solution to render the fireworks to a class 1.4 hazards behavior and still allow for relatively quick consumption in a fire. However, rendering the fireworks to a 4.1 hazards behavior is not likely except for the very smallest of the consumer class of fireworks.

Soaking times vary depending on the type of article. Small consumer fireworks in light paper can be desensitized in as little as one week. Two weeks would be recommended for safety concerns.

Larger articles, such as cakes, mines, multi-shot devices, etc. will require about 4 weeks for proper desensitization and saturation of the heavily wrapped pyrotechnic. Shells will also take about 4 weeks to be fully saturated.

SMS recommends that shells 3 inches and larger be separated from other fireworks for desensitization.

All fireworks, regardless of size or desensitization solutions will, if sufficiently dried out after soaking, return to some level of reactivity greater than when wet. It is unlikely that this level of reactivity will approach the original dry level, but will based on testing performed in this study return to a 1.4 Hazards behavior.

Note of Concern

Testing was not performed on fireworks that are labeled as “water-resistant” or “water-proof”. Many fireworks have water proof fuzes, but the rest of the device will absorb water, thus a water-proof fuze does not indicate a special concern. Water-proof and water-resistant devices will likely have a special coating or be made of materials that resist water penetration into the device. The concern with these devices that are manufactured to be water proof or water resistant is that soaking them in water and possible even diesel may not render them desensitized.

For these special cases, it is recommended that such items be segregated into their own containers and that the containers be filled with either the water or diesel soaking solutions. This will isolate the fireworks and prevent inadvertent exposure to ignition sources. They should retain the original shipping classification of the article until such time as a more appropriate classification can be determined. Containers should be marked as containing water-proof or water-resistant fireworks. Special permitting for shipping may be required.

Task 6: Briefing to PHMSA

Task 6 is a Power Point Presentation of the findings of this study. It contains a summary of the tasks performed, the findings of those tasks and conclusions about the process of desensitization of fireworks. Included are photos and videos demonstrating the process of desensitization and operations of the batch process unit. This briefing is included as Attachment 8 of this final report.

Task 7: Final Report

Task 7 is the final report of this study. This document is the final report. In addition to the final report SMS will provide the files used for attachments to this final report and all pertinent data acquired during the testing associated with this study. Included will be the videos of tests and still photos of tests and materials. Also included will be a power point presentation of the findings of this study suitable for public dissemination. Included in this presentation will be directions and procedures on the process of desensitization of fireworks. The full presentation is Attachment 8. (Attachment 8 will also be used for the PHMSA Presentation, Task 6.)