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Summary Report on Tests on Display Fireworks Conducted by the Bureau of Mines for the U.S. Department of Transportation Relative to Hazard Classification of Display Fireworks

J. Edmund Hay

Formerly: Supervisory Physical Scientist, Pittsburgh Research Center,
U.S. Department of the Interior, Bureau of Mines, Pittsburgh, PA, USA

Introduction

The U.S. Department of Transportation (DOT) requested the U.S. Bureau of Mines to conduct tests on explosive substances and articles in support of the involvement of both agencies with the United Nations (UN) Group of Experts on Explosives pursuant to the development of an international classification system for explosive substances and articles. This request was embodied in Interagency Agreement No. DTRS 5684-X-00315. As a sub-set of the work performed under this agreement, DOT requested the Bureau to conduct special tests on samples of display fireworks (classified as class B fireworks at the time that the tests were done) in their normal shipping cartons. These tests included tests conducted according to the specifications of UN test series 6, and an additional test to determine the consequences of a fire involving a truck loaded with 500 pounds of class B Fireworks. Test procedures and results are reported herein. These tests were performed at a site leased by the Bureau from Consolidation Coal Co. in Harrison County, Ohio, during the period May 28–31, 1985.

The Department of Transportation (DOT) Hazardous Materials Regulations (HMR) published in title 49 Code of Federal Regulations (49 CFR) defines six classes of explosives consistent with the UN classification scheme, of which three are of relevance here, viz. class 1.1, class 1.3, and class 1.4. The general hazards of each class are (49 CFR 173.52):

Class 1.1 explosives — detonation or mass explosion hazard; generally corresponds to the former DOT class A.

Class 1.3 explosives — fire/minor explosion hazard, generally corresponds to the former DOT class B.

Class 1.4 explosives — minimum hazard, generally corresponds to the former DOT class C.

Throughout the text of this report the terms ‘Class A’, ‘Class B’, and ‘Class C’ are used even though no longer applicable, since they were correct at the time that the tests were done, whereas it would not be correct to use the UN terminology since the UN scheme was not in effect at the time the tests were performed and criteria applied were not completely in accordance with UN specifications.

i. Class 1 / Division 1.1 consists of explosives that have a mass explosion hazard. A mass explosion is one that affects almost the entire load instantaneously.

ii. Class 1 / Division 1.3 consists of explosives that have a fire hazard and either a minor blast hazard or minor projection hazard or both, but not a mass explosion hazard.

Table 1. Contents of Package of Ship and Show Fireworks.

(DOT Specification 12B65 fiberboard box 13"×13"×18-½"; Gross Weight 32 pounds)

Manufacturer	Size (diameter, in.)	Identification	Quantity
A	6	Green and silver	1
B	6	Green and silver	1
C	5	Color pearl	1
A	5	Red and green	1
D	5	#403	1
E	4	Red flitter	2
A	4	Blue and silver	2
D	4	#251	1
A	3	Red and green	4
F	3	Red, green and yellow	4
B	3	Green to red peony	2
B	3	Bright red and gold	2
G	3	Red rose	2
H	3	#378	1
C	3	Red and green	2
E	4	Blue and flitter	1
E	4	Red	1
G	4	White rose	2
B	3	Variegated peony	1

iii. Class 1 / Division 1.4 consists of explosives that present a minor explosion hazard. The explosive effects are largely confined to the package and no projection of fragments of appreciable size or range is to be expected. An external fire must not cause virtually instantaneous explosion of almost the entire contents of the package.

The test procedures employed (except for Test 4) represent versions of UN test series 6(a), 6(b) and 6(c); even though the UN classification scheme for explosives was not yet in effect in the U.S. at the time that the tests were done, its adoption was imminent and it was felt that these would be the appropriate test methodologies.

One purpose of the tests described in this report was to determine which of the above explosives classes, if any, should be assigned to the devices known as special fireworks. Another purpose was to evaluate the hazard of 500 pounds of certain fireworks (ship and show) when deliberately ignited in a motor vehicle. With the exception of the salute shells, all the fireworks tested were what is called in the fireworks industry "ship and show" fireworks. "Ship and show" fireworks are packaged fireworks designed for organizations such as Chambers of Commerce who wish to put on a relatively small display. Restrictions placed on these shipments by the industry are:

1) No salute shells.
2) No shells larger than 6 inch diameter.
3) No multi-break shells.
4) No more than 500 pounds gross weight in one vehicle.

Table 1 shows the shells making up a typical "ship and show" package. It is reasonable to assume that, if shells larger than 6 inch had been tested, the explosions and fires observed would have been larger.

Description of Tests

The test procedures and their results are described below.

Test No. 1: This was a test on a single package of assorted display (DOT class B) fireworks. The package was a DOT specification 12B fiberboard container measuring 12.5×13×19 inches, one of the cartons in which the fireworks were originally shipped from the manufacturer. The as-received cartons were not used for the test however, since each one contained fireworks of a different type (star shells, special effects shells, etc.), size, and manufacturer. The as-received cartons were opened and the individual shells were repacked in the carton used for the test so that this carton contained a representative assortment of each of the individual types, sizes, and makers. A list of the types of shells is given in Table 1.

The net weight of the fireworks in the carton was 32 pounds. Two ignitors each consisting of a small plastic bag containing 2 grams of grade FFFg Black Powder and an electric match-head were placed in the center of the carton. The carton was then sealed and laid on a 0.125-inch thick, mild steel witness plate 48×48 inches and was then surrounded and covered by a pile of sand-bags (100 pounds each) so that the thickness of the sand on all sides of and on top of the package was at least 20 inches (.508 meters). The resulting pile measured 53 inches wide × 59 inches long × 33 inches high.

Although not strictly required by the test procedure, four pressure gages (PCB Piezotronics type 112A21) were deployed at a distance of 50 feet in various directions.

Result: The ignitor was fired and a series of small, muffled explosions began inside the sand-bag stack which displaced or destroyed some of the bags so that some of the remaining fireworks exploded under little if any confinement. Burning stars were projected as far as 200 feet from the package.

There was no evidence of detonation: no crater was observed and the witness plate under the carton was neither punched nor dented. The entire contents of the package were consumed, the process taking about 8 seconds. About 15 separate reports could be resolved; considering that reports and flashes from explosion of articles occurring before the sand pile was disrupted would be muffled and obscured respectively, it is not possible to conclude that the greater part of the articles exploded virtually simultaneously.

At this point one of the oscilloscopes was found to be triggering erratically, and two of the pressure gage records were lost. The remaining pressure gages recorded pressures of 0.38 and 0.36 psi, or an average pressure of 0.37 psi at 50 feet.

Test No. 2: This test was conducted on a stack of four packages, each 24×20×13 inches, and identical in contents to the one described in Test No. 1. The four packages were stacked in two layers consisting of two cartons side by side, the total contents were 128 pounds net of miscellaneous class B fireworks, the total volume of the stack was 10,800 cubic inches or 0.177 cubic meters. As in Test No. 1, two ignitors each consisting of 2 grams of grade FFFg Black Powder in a small plastic bag containing an electric match-head, were placed in one of the cartons near the center of the stack. The stack of packages were laid on a 0.125-inch thick mild steel witness plate, as in Test No. 1, and surrounded by a layer of 100-pound sand bags at least 40 inches (1.016 meters) thick on all sides including the top. (A layer of 0.25-inch thick plywood had to be laid over the top of the stack of cartons to keep the weight of the sand from crushing them. The final dimensions of the sand-bag pile were 104 inches wide × 120 inches long × 66 inches high, estimated to be 15 tons of sand. As in shot No. 1, pressure gages were deployed at a distance of 50 feet.

Result: The ignitors were fired and the contents of the stack began to explode, blowing away some of the sand bags, allowing the remainder of the fireworks to explode under little confinement. Burning stars were projected as far as 200 feet from the stack. The entire process consumed about 15 seconds. No crater was formed, the witness plate was found undamaged, and all the fireworks were consumed, as in Test No. 1. Only one pressure gage trace was obtained on this shot recording a pressure of 0.38 psi, virtually identical to that in shot No. 1.

The principal result is that the explosion did in fact propagate throughout the stack, but as in Test No 1, the muffling and obscuration of the explosions by the sand bags made it difficult to establish definitely whether the greater part of the articles exploded virtually simultaneously.

Test No. 3: This test was identical to Test No. 1 in all respects except that the contents of the carton were exclusively 3-inch salute shells, rather than assorted fireworks. Seventy-five shells were placed in the carton which measured 24×20×13 inches, which was provided with ignitors, placed on a 48×48×0.125-inch mild steel witness plate and confined with a 20-inch thickness of sand bags on all sides and the top, as in Test No. 1; two pressure gages were also deployed at a distance of 50 feet as in Test No. 1.

Result: The ignitor was fired and the contents of the carton exploded within about 4 seconds. Almost all of the sandbags were blown away and the witness plate was found to have a depression about 6 inches in diameter and about 0.5 inches deep; the pressure gages recorded lower pressures than expected considering the violence of the reaction relative to Test No. 1, viz., 0.42 and 0.24 psi, or an average of 0.33 psi. All of the fireworks were consumed. Only 8 individual reports could be resolved, out of the 75 expected. Considering the short interval of time involved, and the violence with which the sand pile was disrupted, it is not reasonable to suppose (as might have been the case in Tests 1 and 2) that the other 67 explosions might have occurred one at a time and were muffled. It is concluded that most of the items exploded virtually simultaneously and that a class C classification for salute shells would be entirely inappropriate. Indeed, it is our opinion that if the witness plate had not been used, a crater would have been formed; this, if it had occurred would be evidence suggestive of class A classification.

Test No. 4: This test was designed to determine the consequences of a small load of class B display ("ship-show") fireworks in a small truck being exposed to an external fire. Five hundred pounds of assorted ship-show fireworks in their shipping cartons were placed in the cargo compartment of a small delivery van of about 18 feet overall length. The specific fireworks used in the test are shown in Table 2 (located at the end of this article). The stack of cartons was placed in the left rear corner of the cargo compartment and the exposed (front, right, and top) sides of the stack were surrounded with sand bags to a thickness of 14 inches, to simulate the confinement provided by additional packages. The truck was jacked up so that the floor of the cargo compartment was about 3 feet off the ground. At the request of DOT, one of the pressure gages was placed inside the truck body about 3 feet from the stack of packages; another was deployed at a distance of 100 feet. The space under the truck beneath the stack of packages in the cargo compartment was filled with randomly piled pine blocks approximately 6 inches wide × 16 inches long × 1.5 inches thick, soaked with kerosene and ignited with a small bag of Black Powder containing an electric match-head.

Result: The fire burned for approximately 12 minutes before the packages began to explode. Unfortunately, after 9 minutes the internal pressure gage became inoperative, despite the brass cylinder in which it was inserted which was thought to provide enough thermal inertia to protect it. The explosion of the truck contents proceeded slowly over a period of about 20 seconds, with numerous flaming particles being ejected from the open doors and windshield for distances estimated to be about 150 feet. At the height of the event the truck seemed to be engulfed in flames. All of the fireworks were consumed. Damage to the truck included breakage of glass, numerous indentations of the inner walls, the melting of plastic parts, the thermal buckling of and springing of some seams in the sheet metal, and the scorching of paint. The external gage did not record pressure peaks that could be distinguished from the background noise, an upper limit would be about 0.08 psi. As in Tests 1 and 2, the explosion of the articles proceeded over an extended period of time, and it is not possible to state that the greater part of the articles exploded virtually simultaneously.

Test No. 5: This was a test of 4 cases of assorted class B fireworks packages as in Tests 1 and 2, exposed to an external fire. The four packages containing 128 pounds net weight were stacked on a steel grid about 18 inches off the ground. Beneath this grid, pine blocks ap-

proximately 6 inches×16 inches×1.5 inches were stacked. Aluminum witness plates 48 inches × 96 inches × 0.08 inches thick were set up on frames on 3 sides of the stack of packages, approximately 120 degrees apart; the plates were 13.3 feet (≈4 meters) from the stack and were oriented vertically, facing the stack with their lower edges approximately 2 feet off the ground. Two pressure gages were deployed at a distance of 50 feet and a pyrometer was also deployed at a distance of 50 feet. The wood under the stack was soaked with kerosene, provided with an ignitor as used in Test No. 4, and ignited.

Result: The stack of packages began to explode after about 80 seconds. The explosion of the contents proceeded over a period of about 11 seconds. All of the contents were consumed. The witness plates had numerous impact marks, probably from stars, but no significant indentations — they remained standing after the event. Burning stars were projected as far as 150 feet. The pressure gages recorded pressures of 0.19 and 0.56 psi. The pyrometer recorded a peak thermal flux of 0.12 cal/cm^2/sec of about one second duration, with a 5-second average value of 0.063 cal/cm^2/sec; the period of measurable thermal radiation was about 8 seconds. The pyrometer record also exhibited 3 spikes of short (less than 0.01 second) duration which exceeded the limits of the pyrometer at 1 cal/cm^2/sec; these may have been due to shells ejected from the stack exploding near the pyrometer; they may also represent electrical noise. It was quite evident that, although many individual reports and flashes were heard, the bulk of the items exploded in such a fashion that the individual flashes and reports blended together.

Following this test some unburned stars were found widely scattered around the test site. No intact shells were found however, and the presence of such relatively small amounts of unreacted material does not alter the conclusion that virtually all of the shells exploded.

Test No. 6: This was a repetition of Test No. 3, except that the box contained 73 rather than 75 three-inch salutes; the dimensions of the box were 12.5×13×26 inches. In all other respects the setup was identical.

Result: The result was very nearly the same as in Test No. 3 except that the explosion of the contents proceeded over a period of about 5 seconds, no indentation of the witness plate was observed, and the maximum blast pressures recorded were 0.48 and 0.37 psi for an average of 0.43 psi. The same conclusions as those for Test No. 3 may be drawn here, viz. the overwhelming majority of the items exploded in a period of time too short to resolve, except that the lack of damage to the witness plate did not suggest that the result might have been a detonation.

Conclusions

In every case, complete propagation of explosion throughout the sample, whether in one package or many, was observed. In the case of one of the two tests involving salute shells, there was evidence (i.e., damage to the witness plate) suggesting that the result might have involved a detonation.

The results of the internal ignition tests and the external fire test indicate that a class C explosive classification would not be appropriate for assorted display fireworks. Since these items do not function by detonation, a class A explosive classification is also not appropriate for most of the fireworks tested, and since they function primarily by rapid combustion, it is concluded that a class B explosive classification is appropriate. A question arises as to whether salute shells are ever shipped as they were tested here (i.e., unmixed with other types of shells), and if so whether a class A explosive classification should be considered. In this respect, the results of the testing described above were not completely conclusive.

Summary

This report details tests conducted by the Bureau on class B (display) fireworks for single package, stacked package and bonfire tests, in addition to a special test involving a truck partially laden with fireworks exposed to an external fire. In no case involving ship-and-show fireworks did detonation result, but in all cases explosion propagated to and consumed the entire sample and burning stars were projected for considerable distances. It is concluded that a

proper classification for the fireworks tested, according to DOT specifications, would be class B Explosive, based on the tests performed, although there is a possibility, requiring additional testing to resolve, that salute shells, unmixed with other types of shells in the same package, might be properly classified as class A explosives.

Table 2. Fireworks Used in Truck Fire Test.

	Manufacturer	Size (diameter, in.)	Identification	Quantity
Box 1	C	5	Color pearl	3
(37 lbs)	C	3	Assorted color	32
	D	6	#241, #243	2
	D	4	#337	3
	E	3	#578	20
Box 2	D	6	#254	1
(32 lbs)	D	4	#553	1
	A	3	Red and green	12
	E	4	Red flitter	6
	C	5	Color pearl	2
	E	4	Blue flitter	6
	B	3	Variegated peony	14
Box 3	G	6	Blue diamond	2
(40 lbs)	A	6	Green and silver	1
	A	5	Red and green	2
	A	4	Blue and silver	4
	A	3	Red and green	12
	B	3	Glittering silver chrysanthemum	17
Box 4	F	3	Assorted color	13
(32 lbs)	B	3	Variegated peony	2
	G	6	Blue diamond	2
	E	4	Red flitter	7
	G	3	Red rose	10
Box 5	A	5	Red and green	7
(42 lbs)	E	4	Blue flitter	12
	G	3	White rose	24
Box 6	C	5	Pearl comet	6
	E	4	Red	6
	G	3	White rose	18
Box 7 (39 lbs)	E	4	Red and flitter	31
Box 8	C	5	Color pearl	4
(35 lbs)	E	4	Blue flitter	12
	G	3	Red rose	28

Table 2. Fireworks Used in Truck Fire Test (Continued.).

	Manufacturer	Size (diameter, in.)	Identification	Quantity
Box 9	D	6	#428, #345	2
(37 lbs)	D	5	#403	2
	D	4	#254	2
	D	4	#364	3
	D	4	#327	1
	D	4	#254	1
	D	4	#338	1
	H	3	#578	25
	E	4	Blue and flitter	8
	G	3	Red rose	4
	B	3	Bright red to golden peony	7
Box 10	D	6	#243	1
(38 lbs)	D	6	#245	1
	D	5	#345	1
	D	5	#392	1
	D	5	#241	1
	D	5	#381	1
	D	5	#403	1
	D	5	#357	1
	H	3	#578	19
	D	4	#365	2
	D	4	#252	2
	F	4	Assorted colors	13
Box 11	B	2	Variegated peony	25
(42 lbs)	B	3	Blue peony	25
	B	3	Bright red to gold	25
Box 12	D	6	#245	1
(40 lbs)	D	6	#241	1
	D	6	#344	1
	D	6	#521	1
	D	5	#392	1
	D	5	#391	1
	D	5	#389	
	D	5	#245	1
	D	4	#245	1
	D	4	#245	1
	D	4	#245	1
	D	4	#338	1
	D	4	#363	1
	D	4	#338	1
	D	4	#553	1
	D	4	Green peony	1
	D	4	#363	1
	D	4	#344	1
	H	3	#378	25
	B	3	Bright red to gold peony	20

Table 2. Fireworks Used in Truck Fire Test (Continued.).

	Manufacturer	Size (diameter, in.)	Identification	Quantity
Box 13 (42 lbs)	G	6	Blue diamond	4
	F	4	Assorted colors	12
	B	3	Red, green and gold peony	5
	B	3	Blue	12
	B	3	Glittering silver to variegated chrysanthemum	4
Box 14 (15 lbs)	G	6	Blue diamond	2
	C	5	Color pearl	1
	B	3	Blue peony	9
	B	3	Glittering silver variegated chrysanthemum	4

Future Events Information

If have information concerning future—explosives, pyrotechnics, fireworks, or rocketry—meetings, training courses or other events that you would like to have published in the *Journal of Pyrotechnics*, please provide the following information to the publisher of the Journal of Pyrotechnics:

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