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Fireworks and their Hazards

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"What are fireworks like?" she had asked.

"They are like the Aurora Borealis," said the King, "only much more natural. I prefer them to stars myself, as you always know when they are going to appear...."

Oscar Wilde, *The Remarkable Rocket*

Although appreciative audiences may value the predictability of fireworks, firefighters, unlike the king in *The Remarkable Rocket,* know that on occasion they may not be so reliable. When the first-due company finds it is dealing with fireworks, it is in an unusual situation that requires specific technical knowledge to ensure the safest possible outcome.

Scope of the Challenge

During the past 15 years, the quantity of fireworks used in the United States has more than doubled to approximately 100 million pounds annually. Although fireworks remain most popular over the Fourth of July holiday, their use is now common throughout the year at theme parks, fairs, and public events. Performing artists have greatly expanded the use of pyrotechnic displays to enhance the entertainment value of concerts, plays, and other stage productions. In a recent year, the U.S. Fire Administration reported that approximately 6,000 (less than one percent) of the almost one million fires occurring in the United States involved fireworks. The average loss per incident was less than $2,000.

Pyrotechnics is part of the field of 'high energy chemistry'.[1] Pyrotechnics and explosives differ largely in the rate at which energy (in the form of heat, light, sound, and motion) is released. Pyrotechnic burning and explosion, like all burning, involve oxidation-reduction reactions. The degree of *confinement* of highly reactive compounds and compositions has considerable impact on the behavior of the material. A mixture that simply burns in the open may explode when contained within the hard covering of a fireworks aerial shell.

The local fire authority usually has at least one company standing by at major fireworks displays. Although the transportation safety experience with fireworks has been exemplary, motor vehicle accidents involving trucks carrying pyrotechnic devices can occur at any time without warning. Thus, firefighters and company officers must be aware of the hazards of pyrotechnic devices, understand the differences between the various classes of legal and illegal fireworks, and have basic strategies in mind for dealing with pyrotechnic-related incidents.

The firefighter and company officer may be familiar in a general way with the many guidelines and regulations under which consumer fireworks (DOT Explosives 1.4G, formerly referred to as common fireworks or Class C explosives) sales and display fireworks (DOT explosives 1.3G, formerly referred to as special fireworks or Class B explosives) performances are organized and conducted.

This article focuses on company operations and incident command decisions in dealing with the rare fire, explosion, or hazmat incident involving these devices after they are manufactured. We assume that departments having fireworks manufacturing facilities within their jurisdictions already have conducted extensive preplanning and training to deal with the potential problems they present.

Conflicting Information

Misinformation with respect to fire suppression when fireworks are involved has been promulgated. For example, it is frequently stated that applying water to fireworks or fires involving them is dangerous because of the presence of magnesium, titanium, and other metallic-reducing agents that can have adverse reactions with water. What is the bottom line? When faced with a fire involving display fireworks, does suppression truly present unusual risks and hazards? Can conventional fire suppression techniques implied by the fire tetrahedron be applied? What about the content of metals in pyrotechnic compositions? Will applying water produce more intense burning?

Clearly, the answers to these questions are loaded with potential mishaps. As always, basic principles of fire science and behavior must be applied to ensure reasonable safety, avoid the assumption of unnecessary risk, and maximize the likelihood of limiting property damage, protecting others' lives, and getting home in one piece.

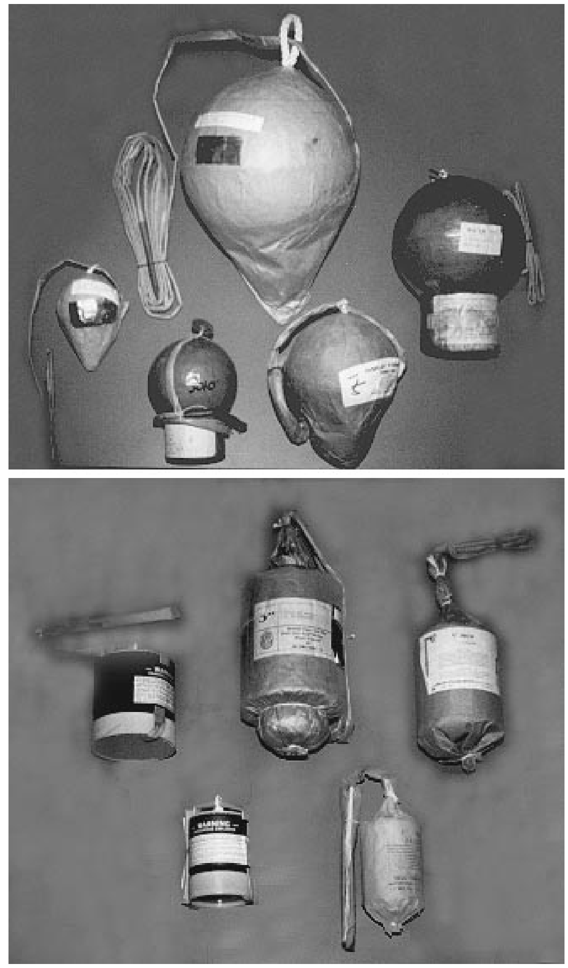

Figure 1. Photos illustrating typical shapes and sizes of display fireworks aerial shells (top—spherical 3–8 inch; bottom—cylindrical 3–5 inch).

Fireworks Composition

In chemical terms, fireworks are a mixture of an oxidizing agent and fuel. Ironically, care is often taken to ensure that color-producing pyrotechnic compositions burn and do not explode per se. An explosion would consume all the pyrotechnic material instantaneously, depriving the viewers of the glitter, glow, and attractive color combinations that characterize modern fireworks. Commonly used oxidizers include potassium nitrate, potassium perchlorate, ammonium perchlorate, and barium nitrate. Fuels (reducing agents) for the oxidizers include aluminum, magnesium, sulfur, charcoal, and carbohydrates (including lactose and natural res-

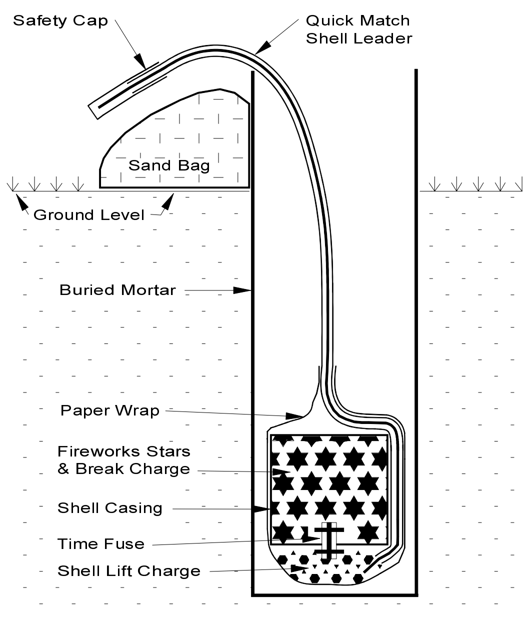

Figure 2. Drawing identifying the components of a typical aerial shell in a buried mortar.

ins). Modern compositions also typically include any of several types of binder and chemical additives to produce specific pyrotechnic effects, such as strontium salts for red color or titanium metal for white sparks.

The Devices

Although skyrockets occasionally are used to deliver display fireworks into the sky, they are relatively inefficient at lifting large payloads and are less predictable in flight than aerial shells. Accordingly, aerial shells are by far the most common display fireworks device. Cylindrical or spherical in shape (Figure 1), shells have a rapidly burning "quick match" fuse that also is used to lower smaller shells into a mortar—a tube, sealed at the bottom end, from which aerial shells are fired (Figure 2). Most commonly, mortars are made of spirally or cylindrically wrapped paper, high-density polyethylene plastic, or steel. Manually fired (hand-lit) shows use a relatively small number of mortars (several appropriate for each shell size being fired), which are repeatedly loaded and fired throughout the performance. Electrically fired performances require preloading every shell into its own mortar; often thousands of mortars are used. See Figure 3. In manually fired shows, a shell typically is launched every five to 20 seconds. Electrical firing makes it possible to launch more than one shell per second and to accomplish the precise timing and choreography typical of the finest shows. Regardless of the type of firing, the mortars are protected from tipping either by partially burying them or securing them in racks aboveground.

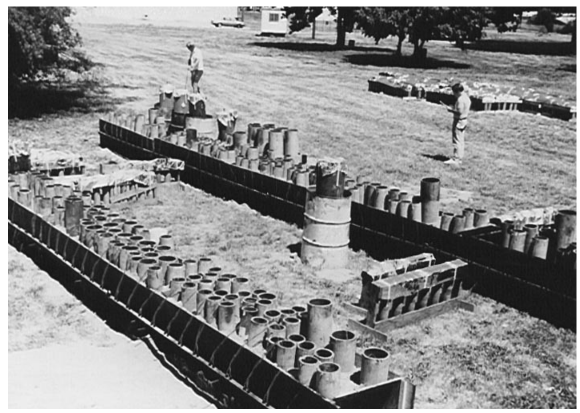

Figure 3. Photo of a typical setup for an electrically fired display where there is one mortar for every shell to be fired.

Although the shell leader (the length of quick match attached to an aerial display shell) may be used to lower the shell into the mortar, it serves primarily as the ignition device. (See Figure 4.) Underneath the shell is a lift charge of Black Powder (also called "gun powder," a mixture of potassium nitrate, charcoal, and sulfur). Ignition of the fuse (by an electric match,[2] a fusee, or similar device) proceeds to ignite the lift charge, which propels the shell up the tube and into the air. Aerial shells range in diameter from less than three inches to more than 12 inches; however, most shells used are between three and six inches. While the shell is hurtling upward, the time fuse between the lift charge and the main shell casing burns for a time calculated to ignite the break charge so the shell will explode just before it reaches its highest point.

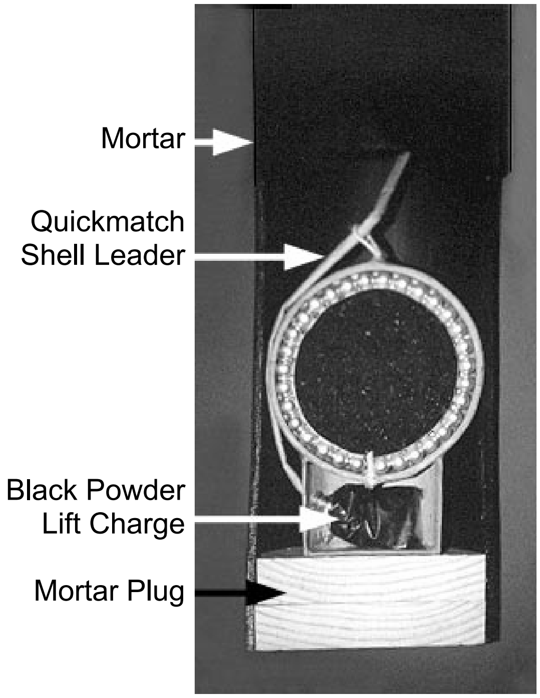

Figure 4. Photo of a cut-away model of an aerial shell in its mortar.

Lift charges (black powder positioned beneath an aerial shell) are of such a size that they typically produce a shell muzzle velocity of approximately 225 miles per hour regardless of the shell's size. The time fuse burns for approximately three to six seconds, depending on the size of the shell, which achieves a height of roughly 120 feet per inch of shell diameter. Thus, a six-inch shell will burst at an elevation of approximately 700 feet above the ground. The burst spread also depends on the size of the shell and may reach approximately 90 feet in diameter per inch of spherical shell diameter. The six-inch shell mentioned above may have a spread of roughly 500 feet; an 8-inch shell has a dramatic spread of about 700 feet (See Figure 5). Design also plays a role; some shells burst broadly while others may be designed to burst in a tight or narrow pattern. See Table 1 for typical fireworks aerial shell performance characteristics.

Figure 5. Photo of an 8-inch aerial shell exploding. Note that inside the small oval area (lower left) is a 1-ton cargo truck.

Table 1. Typical Spherical Display Fireworks Shell Characteristics.

Shell Size	Weight[a]	Burst Height[b]	Burst Radius[c]	Burst Delay[d]
(in.)	(lbs.)	(ft.)	(ft.)	Time (sec.)
3	0.3	400	125	3.0
4	0.8	550	175	3.5
5	1.5	700	210	4.0
6	2.5	775	250	5.0
8	5.5	950	400	6.0
10	11.0	1075	425	6.5
12	18.0	1175	450	7.0

a. The net weight of pyrotechnic materials in aerial fireworks shells is typically about one-half their gross weight. The weights reported here are gross weights for fairly typical spherical fireworks shells.[1]

b. These data, to the nearest 25 feet, are from reference 2 below. There are no published data on the burst height for cylindrical fireworks shells. It is felt they are generally about the same as for spherical shells.

c. These burst radii, to the nearest 25 feet, are for typical high-quality spherical shells.[3] The values were recalculated from data provided by T. Shimizu. Lower quality spherical shells and typical cylindrical shells may have burst radii only 40 to 80 percent of those reported here.

d. These are typical elapsed times, to the nearest half second, between the firing of a fairly typical fireworks aerial shell from its mortar and when it explodes.[4] The delay is provided by a pyrotechnic time fuse. The time fuse is ignited during the firing of the shell, and the shell bursts (explodes) when the time fuse burns through to the interior of the shell.

References for this table.

1) K. L. and B. J. Kosanke, "Shimizu Aerial Shell Ballistic Predictions—Part 1", *Pyrotechnics Guild International Bulletin,* No 7 (1990). Also in *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 2 (1990 through 1992)*, Journal of Pyrotechnics, Inc., Whitewater, CO (1995).

2) K. L. Kosanke, L. A. Schwertly, B. J. Kosanke, "Report of Aerial Shell Burst Height Measurements", *Pyrotechnics Guild International Bulletin,* No. 65 (1991). Also in *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 2 (1990 through 1992)*, Journal of Pyrotechnics, Inc., Whitewater, CO (1995).

3) K. L. and B. J. Kosanke, "Japanese Shell Break Radii", *Pyrotechnics Guild International Bulletin,* No. 59 (1988). Also in *Selected Pyrotechnic Publications of K. L. and B. J. Kosanke, Part 1 (1981 through 1989)*, Journal of Pyrotechnics, Inc., Whitewater, CO (1995)

4) K. L. and B. J. Kosanke, *Lecture Notes for Display Fireworks Practices*, Journal of Pyrotechnics, Inc., Whitewater, CO (1995).

Set- or ground-piece devices produce showers of colored sparks, glowing letters or figures, or spinning fireworks near ground level. (See Figures 6 and 7.) Although they often burn at very high temperatures, they have little explosive potential. These devices, however, are commonly used and may be found near materials with explosive potential.

In addition to the commercially manufactured consumer and professional display fireworks, illegal explosive devices remain surprisingly common. These federally prohibited explosive devices are commonly known as "M-80s", "blockbusters" or other names denoting powerful explosive capabilities. The U.S. Consumer Product Safety Commission restricts the content of ground firecracker-like devices to a maximum of 50 mg of explosive composition. The old commercially available "cherry bomb" typically contained up to one gram (1,000 mg) of explosive composition. The illegal M-80-type devices typically contain anywhere from 2 to 10 grams (2,000 to 10,000 mg) of explosive

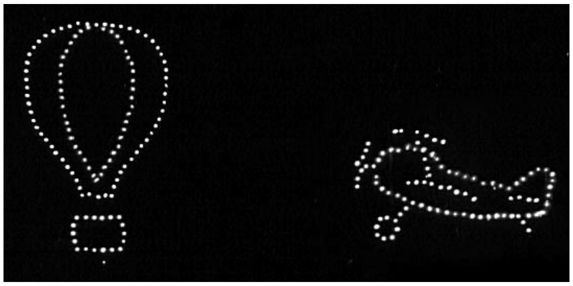

Figure 6. Burning lancework depicting a hot air balloon and an airplane.

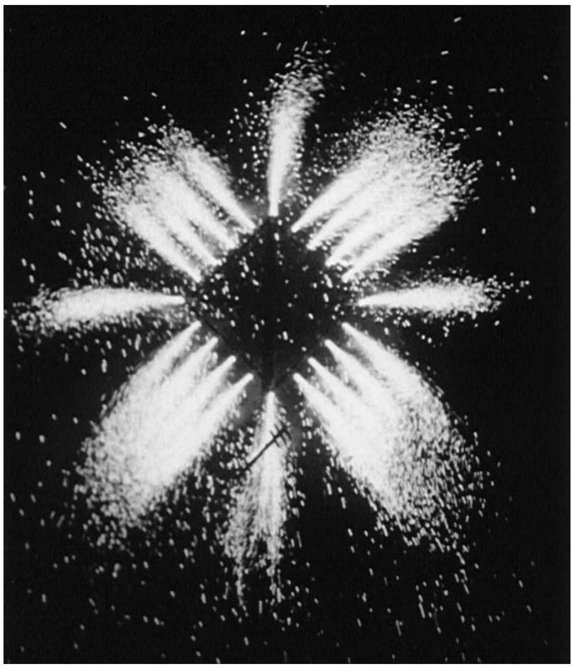

Figure 7. Fountain set piece producing multiple sprays of sparks.

composition. Note that such illegal fireworks cause many of the serious fireworks-related injuries.

Explosive Potential

The net weight of pyrotechnic materials in an aerial fireworks shell (Class B) is typically about half the total weight. Typical consumer fireworks (Class C) generally contain approximately 25 percent pyrotechnic material.[3] The remaining matter is usually a mixture of paper, plastic, and inert substances such as clay. Large quantities (approximately 15,000 pounds) of a mixture of consumer fireworks of various types

Figure 8. Photos of typical consumer fireworks items.

(See Figure 8.) were tested in a fire situation when moderately confined (in large metal cargo containers).[4] In the two tests conducted, the time required for most of the pyrotechnic content of the fireworks devices to be consumed was more than 20 minutes and the burning of pyrotechnic material continued for about an hour. In neither of the tests was there a mass explosion. As a part of public displays conducted by the Pyrotechnic Guild International, huge quantities of firecrackers (more than three million individual firecrackers) have been ignited en masse. Doing this has never produced a mass explosion.

Figure 9. Photo of a box of 3-inch display fireworks shells.

We know of no situation where the burning of even massive amounts of consumer fireworks has produced what could accurately be described as a mass explosion. Large quantities of consumer fireworks (typical of those that might be encountered in a transportation vehicle on fire or a consumer fireworks stand on fire) will be expected initially to burn faster and hotter than the same mass of ordinary combustible material, especially when in an oxygen-limited environment. The reason for this, of course, is that the pyrotechnic material contains its own oxidizers. However, the total fuel load of consumer fireworks will be somewhat less than an equal weight of other combustible materials, since most of the pyrotechnic composition (typically about 70 percent) is actually oxidizer and not fuel.

The spread of fire will be more rapid for large quantities of consumer fireworks than for an equal weight of simple combustible material such as cotton and wood, because of the faster and hotter burning. In many cases, firebrands are propelled a distance away from the burning materials. Firebrands can significantly increase the rate of fire spread especially where many fireworks items are exposed, such as at a large retail sales outlet. Such rapid spread by firebrands, however, will occur to a much lesser extent in a location where the fireworks are stored in shipping cases, such as in a wholesale storage building or vehicle.

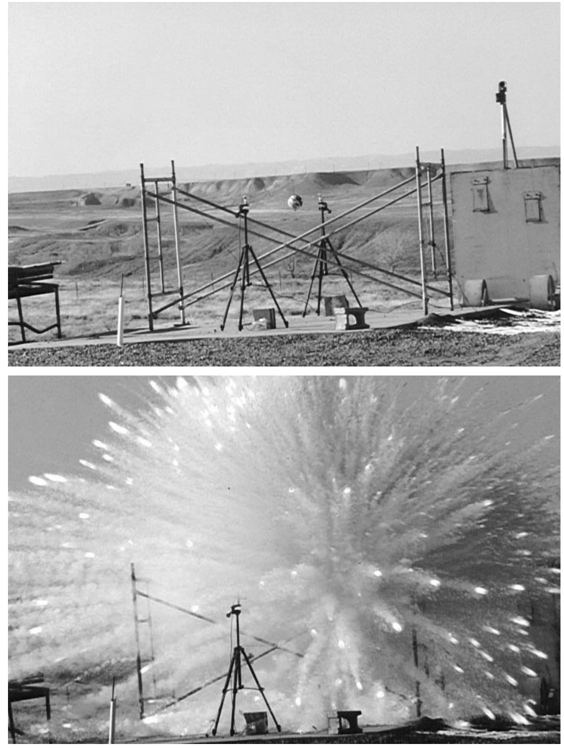

Figure 10. (Upper) Setup for measuring the explosive pressure produced by a display fireworks shell, seen suspended in the middle of the photo. (Lower) Explosion produced by the exploding aerial shell.

Exploding Display Fireworks Shells

While all display fireworks aerial shells (see Figure 9) have significant explosive potential (see Figure 10), the damage potential differs greatly between two primary groups: star shells and salutes. Star shells (those intended primarily to have colored visual effects) are spherical and cylindrical. Their performance in a fire situation will depend on size, but will be largely independent of shape. Salutes are shells that are usually cylindrical and generally less than five inches in diameter. They contain flash powder and are designed to produce an extremely loud explosive noise associated with a white flash of light. The explosive output of salutes and fireworks shells containing reports (functionally small salutes within a star shell) also depends on their size but is substantially greater than star shells of the same size.

The output of various explosives is sometimes compared with the explosive output of TNT (trinitrotoluene), the so-called TNT equivalent. The TNT equivalent determined for an explosive will depend on the method of comparison. Accordingly, the same explosive will have several different TNT equivalent values, one for each method of comparison. Depending on the test method, widely varying TNT equivalent values can be obtained. For example, the air blast pressure of two devices may be similar, but the shattering ability could be very different. What is the hazard posed by being adjacent to an exploding consumer fireworks device or a display shell? Obviously, there is no simple answer, since the explosive output certainly depends on the size and type of the shell, and both the air blast and projection hazards will vary with the distance from the explosion. A three-inch salute with a net pyrotechnic weight of approximately 2.5 ounces produces an air blast roughly equivalent to 1.5 ounces of TNT—clearly enough to produce injury.

In general, standard firefighting personal protective equipment will afford more than adequate protection for fire suppression activities when dealing with consumer fireworks. On the other hand, being in close proximity to an exploding salute several inches in diameter—or even a medium-sized star shell—could seriously injure or possibly kill a firefighter in standard personal protective equipment. Being in close proximity to multiple exploding shells is quite likely to seriously injure or kill a firefighter in standard personal protective equipment.

Explosions of display fireworks produce blast waves, supersonic air shock waves, which, depending on their strength, may have the potential to break windows, perforate eardrums, knock down walls, etc. The strength of blast waves decreases rapidly with increasing distance from the explosion. For display fireworks, the blast wave from an individual aerial display shell will dissipate enough within 30 to 50 feet to be below what can cause serious injury.

Projectiles from explosions may be produced by the exploding device itself or by the blast wave as it mobilizes materials in the area of the explosion. In the case of star shells, some of the projectiles will be burning pellets of pyrotechnic composition (the stars), which will have the ranges indicated in Table 1. For salute shells, the explosive force generally is sufficient to mobilize materials from the environment in the immediate area of the explosion. Both the stars and environmental debris have the potential to produce serious penetrating injuries to those nearby.

With display fireworks, the nature and force of the explosion will depend on a number of factors, including the type of shells (star shells, salutes, or a mixture), the size and number of the shells, the type of shell construction, and the manner of packaging. Accordingly, there will be a range of possible explosive effects. At one extreme, consider a situation in which a large number of large and weakly constructed salutes are in close proximity to each other. In this scenario, it is quite likely that there will be a single mass explosion in which the entire explosive contents of all the shells are consumed in less than a few hundredths of a second after the first salute explodes. In such a scenario, when the first shell's lift charge ignites, the flash of fire ignites its time fuse and likely will cause many more shells and their lift charges to ignite. However, this would not in itself produce an explosion, since the lift charges are in small discrete units and are not tightly confined. Nonetheless, it would definitely produce a fireball and result in the ignition of the time delay fuses on many of the neighboring salute shells. After the delay expected for the size of the shell, the fuse of the first shell will ignite the explosive contents of that shell, producing an explosion. As that shell explodes, it immediately will destroy and explode adjacent salutes, which will continue the process by destroying and exploding additional adjacent shells in a nearly instantaneous chain reaction. The power of such a mass explosion almost certainly will destroy the structure housing the shells, potentially seriously damage nearby structures and even damage distant structures.

Although this is definitely an example of an extremely rapid exothermic chemical reaction, the explosion will not have the same intense shattering ability as most commercial high explosives. For example, while the scenario described above could certainly bend a steel plate and hurl it a large distance, it would not be able to shred the plate into shards of shrapnel. At the other end of the spectrum, consider a situation where there are relatively strongly constructed star shells. In this case, although a powerful explosion still would be produced, the blast pressures would be much lower; but the total duration of the explosive chain reaction likely would be much longer. In this scenario, when the first shell's lift charge ignites, the flash of fire would likely ignite many more shells and their respective lift charges. As with the salutes, ignition of the lift charges would not produce an explosion by itself but would result in a fireball and the ignition of the time fuses on adjacent star shells. When the first shell explodes, the force of the explosion will be much less than that of the salute and probably would be insufficient to cause the immediate destruction and explosion of adjacent shells. However, the force of the explosion is certainly sufficient to propel some of the shells, with their time fuses now ignited, some distance. The burning contents of the first shells are likely to cause the lift charges of other nearby shells to ignite. Within seconds, the fuses of other shells will burn through, and those shells in turn will explode at various closely spaced times. This sequence will create a chain reaction somewhat like that described for salutes above, but with the following two significant differences. First, instead of one massive explosion in much less than one second, a rapid series of smaller explosions spread out over several seconds would occur. Second, there is a much greater chance that the closely spaced but non-mass destructive explosions will propel other ignited aerial display shells up to hundreds of feet from the site of the initial explosion. After a few seconds, those shells will explode, creating additional risk.

In summary, when multiple display shells are involved in a fire, one or more explosions will almost certainly occur. When consumer fireworks alone are involved in a fire, there virtually never will be a significant explosion.

Transport Vehicle Fires

Based on the available research,[4] a semi-trailer fully loaded with consumer fireworks may produce an impressive fire, but it would be much smaller than that caused by a similar-sized trailer of flammable liquid. There is virtually no possibility of a mass explosion. In a warehouse or trailer fire only involving consumer fireworks, responders might scarcely be aware of the presence of fireworks unless the firecrackers popped or special devices whistled.

A fire involving a similar load of display fireworks has essentially the same potential for a powerful explosion as a stationary magazine loaded with a similar type and amount of display fireworks. They present a very dangerous situation.

Ground Fires at Display Sites

Burning debris commonly falls to the ground during fireworks displays. Display operators will take steps to avoid having the potentially hot debris directly contact unexploded fireworks. Fire personnel responsible for site safety should encourage the removal of combustibles from the fallout area before the display begins. When this proves impractical, an alternative would be to water down combustible materials immediately prior to the display. When the combustible material in the fallout zone is dry ground cover, a controlled burn of the ground cover a few days in advance of the display should be considered as an alternative to watering down the site.

Occasionally during a display, a ground fire may occur within the fallout zone. You should not be present in the fallout zone during the display, in part because this is the area in which dud shells are intended to fall. These aerial display shells leave the mortar but fail to burst in the air and subsequently fall to the ground, where they occasionally ignite from the impact. Some of them weigh 10 pounds or more and return to the ground at speeds in excess of 100 miles per hour. In addition, low-breaking shells, which produce an air blast and high-velocity burning material, may explode immediately above the fallout area. Finally, although unlikely, it is possible that dud shells or components from incompletely consumed shells already may have fallen into the area and could explode as a result of the ground fire. Generally, if the ground fire seems unlikely to grow to dangerous proportions during the time remaining for the display to be completed, consider delaying control measures until the display has been concluded. If it is not possible for the display to be completed first, the display should be halted. Careful preplanning and communication immediately before the show is fired will enable intelligent decisions to be made about the placement of water on a ground fire from a relatively safe distance.

Disposal Considerations

Just about the only way to render fireworks completely safe from their fire and explosion hazards is to release their chemical energy. This can be accomplished by either functioning individual items or, when safe, by burning. *Burial is never an acceptable method of disposal.* First, there is unacceptable environmental contamination. More importantly, even in wet ground, the relatively waterproof casing will preserve the explosive potential of the device for surprisingly long periods of time. The disposal of illegal explosives, such as M-80s, cherry bombs, and similar larger devices, should be under the control of bomb-disposal personnel.

Damaged, incompletely burned, or contraband consumer fireworks can be burned safely in large screened containers. One method, developed by the Chicago Police Department, uses large trash dumpsters that have been modified by cutting large holes in the sides and bottom and welding expanded metal screen over the holes. About 500 pounds of consumer fireworks, still in their cases, are loaded loosely into each modified dumpster and ignited by tossing a lighted fusee into the dumpster. Loose loading of the cartons is necessary for good air circulation, which aids in the relatively fast and complete burning (typically about 20 minutes per dumpster). Screened burning in a pit using an accelerant and remote ignition may be acceptable if the ignition of ground cover is not a problem.

Disposing of display fireworks is much more difficult because of the potential for dangerous explosions. When possible, the most desirable method for disposing of small numbers of display fireworks is to have the display operator remove the items from the site and transport them back to the facility of origin for salvaging or disposal there. When a small number of display fireworks must be disposed of at the site of a fire or performance, soaking in water (especially the fuse), then burning the devices individually in a small pit is probably the safest procedure overall. This process requires careful supervision by persons knowledgeable in pyrotechnics or bomb disposal, since the items may function normally with their full explosive potential. However, more often, the item does not ignite until the casing has been burned through, in which case it generally burns safely without explosion.

Fire Suppression

To summarize, fire suppression at incidents involving only consumer fireworks will present few surprises or unusual challenges or dangers if standard operating procedures are followed. Fires involving, or with a potential to involve, display fireworks or illegal explosives present an immediate life threat to fire suppression personnel. When fires involving display fireworks are encountered, a defensive perimeter should be established, and personnel must not be put at risk with direct fire suppression, unless the incident commander believes the potential benefit of a probable rescue outweighs the high risk. Remember that display fireworks are explosives, and in general, fires involving explosives should not be fought.

Since pyrotechnic materials contain their own oxidizers, methods that simply separate the fire from oxygen in the air will not be successful. Using large amounts of water will be successful, however, since the water removes enough heat to keep the materials below their ignition temperatures.

Pyrotechnic devices routinely contain metallic fuels, such as aluminum, that can react with water to produce ignition or even explosion. However, the likelihood of this being a practical problem is greatly overstated in most writings about fireworks materials—that is to say, the conditions under which this could be a problem are quite unlikely and fairly easily controlled. Consider first that most pyrotechnic materials do not become sensitized in any way by the addition of water, especially if that is a large quantity of water. In fact, the vast majority of fireworks compositions are made wet with water during their manufacture. The misconception regarding water comes from accidents that have occurred at manufacturing sites, where relatively large amounts of pyrotechnic composition have become hot and damp for extended periods of time.

Those metals that do have the potential for water reactivity generally produce their effects by burning so hot (greater than 7,000 °F for magnesium) that exposed water dissociates into oxygen and hydrogen. The quantities of reactive metals in pyrotechnic compositions are simply too small to create a threat from the addition of water. This reassurance clearly does not apply if drums of metallic powders such as those likely to be found at a fireworks manufacturing site are involved.

In addition to the reasons suggested above for not engaging in suppression of fires involving fireworks, there is another generally applicable reason. Any items containing pyrotechnic materials remaining after the fire will probably be hazardous waste needing to be disposed of, probably by burning. Accordingly, if it is safe to do so, why not just let the material burn completely in the first place?

Fireworks Stand Fires

In fireworks stands, or even large retail outlet stores with retail consumer fireworks, the rate of fire spread is likely to be such that full involvement will occur by the time the first-due engine company arrives. Note that for a properly configured sales location, the rate of fire spread should not be so great that people should have much difficulty fleeing. On arrival, it probably is prudent not to mount an interior attack. Even though there is virtually no potential for mass explosion and the fire probably will be significantly less intense than commonly imagined, there is still some potential danger to firefighters from rockets and small aerial shells igniting in the fire. Standard personal protective equipment will provide substantial protection from serious injury; however, there still may be significant physical discomfort from being struck by such projectiles. Although the range of such projectiles will be less than 300 feet, they may function where they land and ignite other materials.

Fireworks Manufacturing Site (Consumer or Display)

National Fire Protection Association (NFPA) and Bureau of Alcohol, Tobacco and Firearms (ATF) regulation changes over the past 10 years have resulted in safer designs and requirements for manufacturing sites. Nonetheless, by ATF regulation and NFPA 1124, *Code for the Manufacture, Transport and Storage of Fireworks*, 1998, as much as 500 pounds of pyrotechnic materials of all kinds or 10 pounds of flash powder may be in any one structure or area—a quantity certainly sufficient to produce a dangerously powerful explosion. In addition, although it is beyond the scope of this article, suffice it to say that fireworks manufacturing facilities are designed with separation distances and barricades that should ensure only a modest danger of fire spreading from one structure to another. Accordingly, attempting to fight a fire at a manufacturing site is quite dangerous, and there generally is very little reason even to attempt it.

Epilogue

The information presented in this article is based on the most current data regarding fireworks, their composition, and manner of functioning, as well as on our opinions. Realize, however, that many aspects of fireworks and their behavior have not been well studied scientifically, particularly in fire situations. Accordingly, while the recommendations made herein are thought to be correct and generally applicable, they cannot be absolutely guaranteed. As always, the incident commander must exercise his best judgment based on available background information as well as on the scene situation.

Acknowledgement

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Endnotes

1) J. A. Conking, *Chemistry of Pyrotechnics*, Dekker, New York, N.Y (l985). An outstanding text for background information.

2) Electric match, or fireworks igniter, consists of wire terminating at a relatively high resistance bridgewire surrounded with a small quantity of heat-sensitive pyrotechnic composition. When sufficient electric current is passed through the wire, the heat generated ignites the pyrotechnic composition, producing a small burst of flame. That flame typically ignites a fuse connected to one or more fireworks aerial shells.

3) K. L. Kosanke, "Net weight of explosives", *Fireworks Business*, No. 132 (1995).

4) J. A. Conkling, "American Fireworks Manufacturing and an Industry in Transition", NFPA *Fire Journal*, Vol. 80, No. 5 (1986) p 50–52.