Lecture Slides for Fireworks Display Practices

by

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with additional input from

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Preface

These class notes are intended for use in a training course (lasting several days) on the practical and safety aspects of performing manually discharged fireworks displays. In addition to the lectures, the training includes numerous video and live demonstrations, as well as student exercises. Even if the current training is scheduled for less than a full week, for the sake of completeness, the full set of notes has been provided. However, in that case, some of the lectures included in the notes will have been eliminated along with some demonstrations and exercises, and other lectures will be abbreviated.

Each page of the notes are copies of six of the PowerPoint slides used in the lectures. To make the notes more useful after the completion of the course, the information presented on each page of notes was made to be reasonably complete.

An attempt has been made to have these notes be reasonably consistent with the NFPA-1123 (2006) *Code for Fireworks Display*.

CAUTION

Unless proper procedures are followed, the performance of fireworks displays can pose danger to the display crew and the public. Thus it is felt to be important for the reader to be duly cautioned. Anyone without the required training and experience should never attempt the use of display fireworks. Also, the amount of information presented in these lecture notes, even if accompanied by the full set of lectures and student exercises is not a substitute for the necessary training and experience.

A major effort has been undertaken to review this text for correctness. However, it is possible that errors remain. Further, it must be acknowledged that there are many areas of fireworks in which there is much “common knowledge”, but for which there has been little or no documented research. For the sake of completeness, these notes contain some of this unproven common knowledge. It is the responsibility of the reader to verify any information herein before applying that information in situations where death, injury, or property damage could result.

Table of Contents

Hazard Management for Fireworks

- Accidents, law suits and regulation
- Definitions:
  - Hazard, Risk & Safe
- Hazard management:
  - Recognition, Evaluation & Control
- Display operator responsibilities

Accidents, Law Suits & Regulation

- Fireworks are not unreasonably dangerous when properly used.
- A recent study found that people are 3 to 5 times more likely to be killed or seriously injured driving to view a display than they are to be killed or seriously injured by the fireworks in the display.

Accidents, Law Suits & Regulation

- Most accidents result from carelessness, misuse or failure to follow regulations.
- Spectators and crew members are needlessly injured or killed because of failures to recognize and take seriously the potential danger of fireworks.

Accidents, Law Suits & Regulation

- Lawsuits and regulation are the natural result of accidents that produce injuries.
- This is a chain of events:
  Accident → Injury → Litigation → Legislation (Regulation)
- The only practical point to break this chain is to limit accidents, especially those involving injuries.
- Do this by using Hazard Management.

Hazard And Risk Defined

- These two terms are often confused.
- <u>Hazard</u> is the potential consequences of an event (i.e., its intrinsic potential for harm to persons or property—however infrequently that event may occur).
- <u>Risk</u> arising from an event considers both the intrinsic hazard of the event and the likelihood that event tends to occur.

Safe Defined

- A typical dictionary definition of "safe":
  "Anything involving no risk of mishap, error, etc."
- By this (poor) definition of safe, nothing mankind does is safe because there is always some "risk of mishap" in literally every possible activity.
  - For example, crossing the street, eating food, reading book.

Safe Defined

- The definition from hazard management:
  "Something is safe when the attendant risks are below an acceptable level."
- This definition recognizes that nothing one does is completely free of the possibility of injury and something is considered safe when the probability for injury is sufficiently small.
- This is the definition used in this course.

Hazard Management

- The three basic elements of all hazard management programs are:
  - RECOGNITION of the potential hazards in the activity.
  - EVALUATION of the risks posed by the hazards.
    - By considering both the severity of the consequences and the likelihood of occurrence of an accident.
  - CONTROL by minimization of the risks.

Recognition of Fireworks Hazards

- Fireworks present a level of hazard greater than many realize. For example:
  - Salutes → an air blast equivalency in excess of 50% of their weight in TNT.
  - Shells → leave the mortar at about 200 mph; for a large shell this is nearly the energy produced by a small car traveling at 20 mph.
  - Firework stars → may burn at temperatures greater than 3600 ºF.

Recognition of Fireworks Hazards

- Fireworks present a level of hazard greater than many realize. For example:
  - Dud shells → can fall traveling about 125 mph. Even a relatively small shell can cause death if a person is struck on the head.
  - Large shells → can explode with a blast pressure significantly greater than a military hand grenade, can produce an intense fire ball and may generate potentially life threatening fragments.

Evaluation of Risk

- Risk assessment has two components that involve determining or estimating:
  - The probability of a mishap occurring.
  - The severity of the consequences if the mishap does occur.
- A minor risk has a low probability or a minimal consequence.
- Risks are least when the consequences are minor AND the probability is low.

Evaluation of Risk

Activity	Consequence	Probability	Risk
Jumping off tall buildings to see if you can fly			Is this risk acceptable?

Evaluation of Risk

Activity	Consequence	Probability	Risk
Jumping off tall buildings to see if you can fly			Unacceptable

Evaluation of Risk

Activity	Consequence	Probability	Risk
Jumping off tall buildings to see if you can fly	Crash landing (Severe)	Very High (≈100%)	Unacceptable

Evaluation of Risk

Activity	Consequence	Probability	Risk
Jumping off tall buildings to see if you can fly	Crash landing (Severe)	Very High (≈100%)	Unacceptable
Swimming in the ocean			Acceptable

Evaluation of Risk

Activity	Consequence	Probability	Risk
Jumping off tall buildings to see if you can fly	Crash landing (Severe)	Very High (≈100%)	Unacceptable
Swimming in the ocean	Being eaten by sharks (Severe)	Very Low (≈0%)	Acceptable

Evaluation of Risk

Activity	Consequence	Probability	Risk
Jumping off tall buildings to see if you can fly	Crash landing (Severe)	Very High (≈100%)	Unacceptable
Swimming in the ocean	Being eaten by sharks (Severe)	Very Low (≈0%)	Acceptable
Flipping a coin to decide what TV program to watch	The other program is better. (Inconsequential)	High (50%)	Acceptable

Examples of Fireworks Risk Control

- **To reduce the probability of an accident occurring:**
  - **Inspect all aerial shells for damage and do not use any suspect shells.**
  - **Keep electric matches shunted when possible and their safety shrouds in place.**
  - **Protect aerial shells and other fireworks from damage due to moisture.**

Examples of Fireworks Risk Control

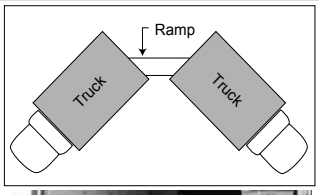
- To reduce the consequences of an accident:
  - Keep unnecessary personnel out of the fireworks discharge area.
  - Sandbag or barricade the fireworks mortars when manually firing aerial shells.
  - Separate the storage areas for fireworks from areas where fireworks are being prepared.

Examples of Fireworks Risk Control

- Often risks can be minimized using methods that require little or no additional effort or expense. For example, consider:
  - Transferring loads between two trucks.
  - Off-loading at the display site.

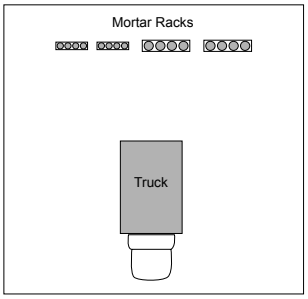
Examples of Fireworks Risk Control

- Transferring fireworks between trucks, they should be angled one to another and a ramp used between them. [Why?]
- [Video? – 4 min.]



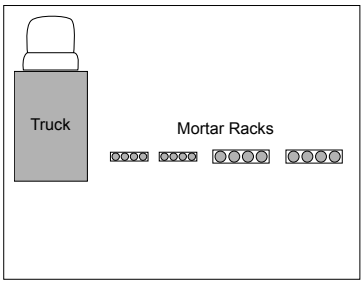
Examples of Fireworks Risk Control

- It is common to position the truck carrying the fireworks as shown to the right.
- But, is there a safer way that is no more work?



Examples of Fireworks Risk Control

- Why is this a safer arrangement?



Display Operator's Responsibilities

- Display Operator: The person with overall responsibility for safety, and the setting up, discharge and tear down of an outdoor fireworks display.
- The operator's responsibility:
  - With regard to the Public:
    - No single failure of fireworks or equipment can be allowed to injure a member of the public.

Display Operator's Responsibilities

- **With regard to the Crew:**
  - **Training: Tell them the correct way and WHY.**
  - **Crew Size: Do not have too many or too few.**

Display Operator's Responsibilities

- **Consider why a Sponsor is willing to pay for a display.**
  - **Good public relations / favorable press coverage**
- **With regard to the Sponsor and the Display Company:**
  - **First and Foremost: A Safe Show.**
  - **Second: A Great Performance.**

Display Operator's Responsibilities

- **Operator Participation:**
  - **Before and after the display — Oversee and check on the proper completion of all work.**
  - **During the display — Monitor safety and crew performance and take all needed corrective measures.**

Assistant's Responsibilities:

- **Assistant: A person who works under the direct supervision of the Display Operator.**
- **Assistant's Responsibility:**
  - **When in doubt – ASK.**
  - **When not in doubt – THINK TWICE.**
  - **Be ever mindful of your own safety as well as that of spectators and the rest of the crew.**

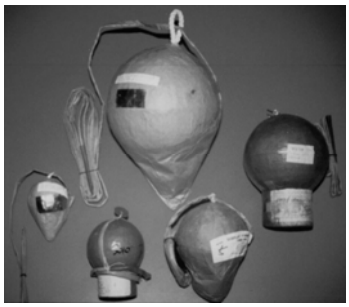
End of Unit

Aerial Shell Construction and Manner of Functioning

- Fireworks shell shapes and sizes
- Basic shell construction
- Shell's manner of functioning
- Shell components discussed:
  - Shell leader, lift charge, time fuse, stars, shell inserts, burst charge & shell labels

Aerial Shell Shapes And Sizes

- Aerial shells are the most commonly used type of display fireworks.
- Basic styles:
  - Spherical



Aerial Shell Shapes And Sizes

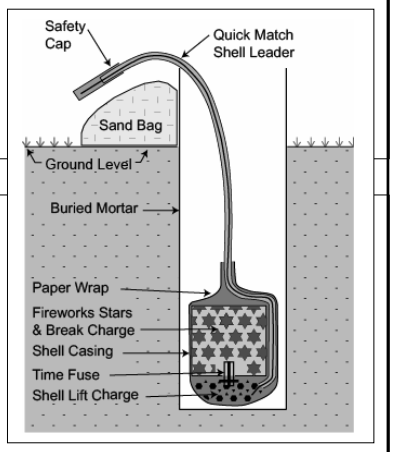
- Basic styles (continued):
  - Cylindrical

Aerial Shell Shapes And Sizes

- Aerial shells range in size from less than 2 inches to more than 12 inches.
  - Most shells are between 2.5 and 6 inches.
- The size of shells is given as the internal diameter of the tube (fireworks mortar) from which they are designed to be fired.
- Because of the need for clearance, actual shell diameters are less than their nominally stated size. (Most 3-inch shells are about 2.7 inches in diameter.)

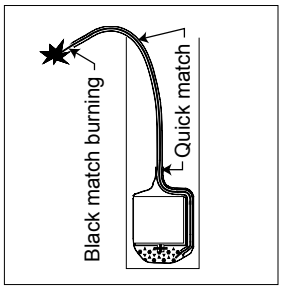
The Basic Cylindrical Aerial Shell Components

- To be discussed later in detail.



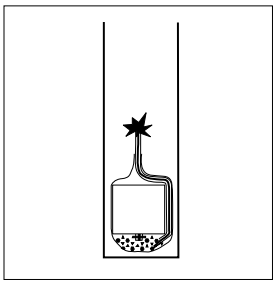
Manner of Aerial Shell Functioning

- A shell is a ballistic projectile fired from a tube (a mortar).
- The safety cap is removed and the delay element is ignited providing 2 to 6 seconds of delay.



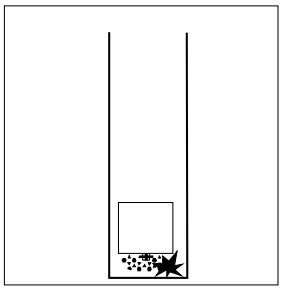
Manner of Aerial Shell Functioning

- When the burning reaches the start of the quick match portion of the shell leader, it burns quickly, in about 0.3 second.



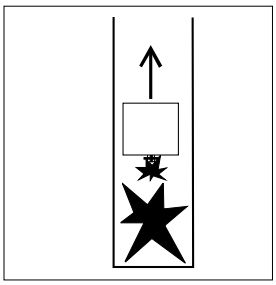
Manner of Aerial Shell Functioning

- When the burning shell leader fuse reaches the Black Powder lift charge, it is ignited.



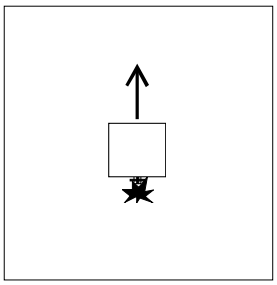
Manner of Aerial Shell Functioning

- The burning lift charge produces combustion gases that propel the shell upward and ignite the shell's time fuse.



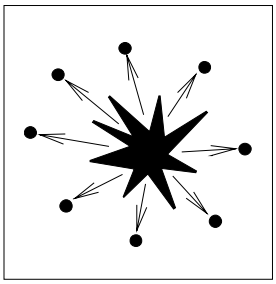
Manner of Aerial Shell Functioning

- The aerial shell exits the mortar in approximately 0.05 second and coasts upward while the time fuse burns.



Manner of Aerial Shell Functioning

- The time fuse burns through to ignite the burst charge and stars in the shell. Then the shell casing bursts to expel the burning stars in a display of light.



Firework Mortars

- The mortar is essential to properly fire the shell into the air.
- The fit of the shell in the mortar determines how much lift gas will escape. A proper fit will propel the shell to a safe height.

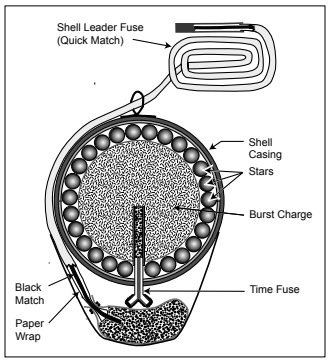
Firework Mortars

- **The fit of a shell in a mortar must be "close but freely sliding".**

- **Thus, each different size aerial shell requires a different size firework mortar.**

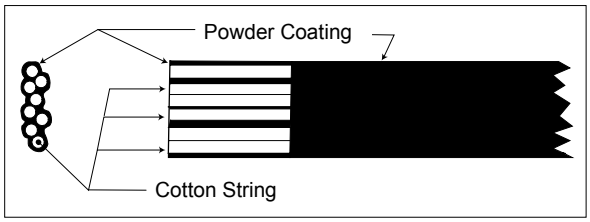
Basic Spherical Shell Components

- **Illustration of the components of a spherical aerial shell.** (To be discussed on the slides that follow.)



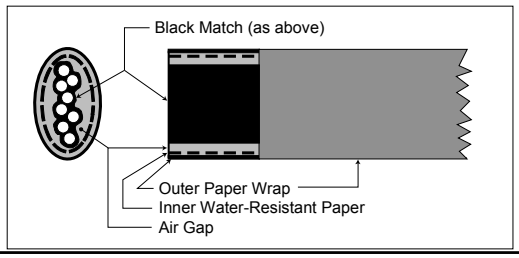
Black Match and Quick Match

- **Black match is made by coating a slurry of Black Powder on cotton strings, to produce a fuse about 1/8" x 1/4" in cross section and burns about 1 inch/second.**



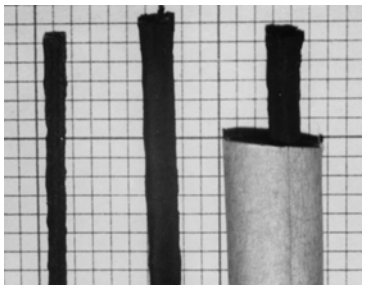
Black Match and Quick Match

- **Quick match is made by wrapping black match with a loose paper covering and burns about 15 feet/second about 200 times faster than black match.**



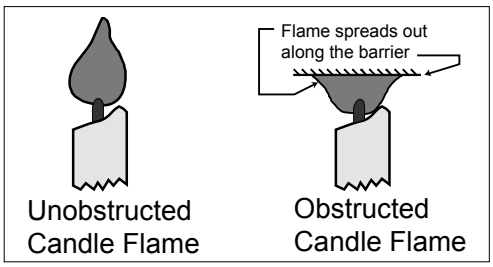
Black Match and Quick Match

- **Examples of two thicknesses of black match and one example of quick match.** [0.1 inch (2.5 mm) per division]



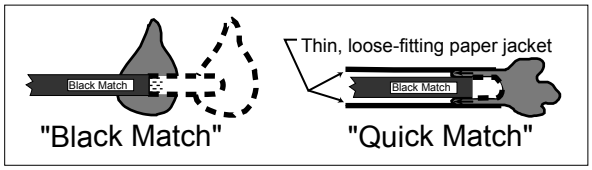
Mechanism of Quick Match Burning

- **The rapid burning of quick match can be explained using the analogy of a candle flame.** [T. Shimizu]**.**



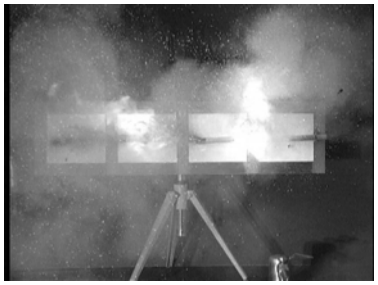
Mechanism of Quick Match Burning

- **Black match burns like an unobstructed candle flame. Quick match burns much faster because its flame spreads along the paper wrap (like an obstructed candle flame) igniting more and more powder.**



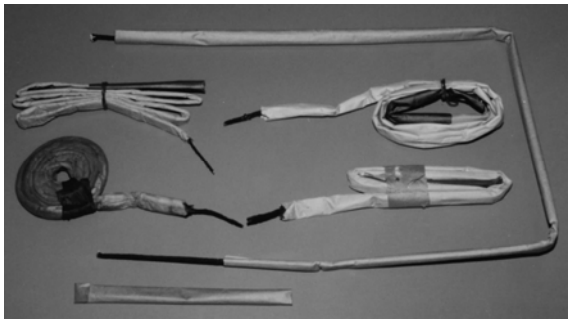
Black and Quick Match Burning

- **Video demonstration of black and quick match burning. [2 min.]**



Shell Leaders

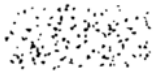
- **Various examples of shell leaders.**



Fireworks Lift Charge

- **The propellant for aerial shells is granular Black Powder (gun powder) made of an intimate mixture of 75% potassium nitrate, 15% charcoal and 10% sulfur. It is referred to as “lift powder” or “lift”.**
- **Finer granulations are used for smaller fireworks shells and coarser granulations are used for larger shells. Spherical shells use finer granulations than the same size cylindrical shells.**

Fireworks Lift Charge

Grade	Appearance	Typical Use
2FA		Cylindrical shells 3-inch and larger
4FA		Cylindrical <3" Spherical ≥ 3"
5FA		Spherical shells smaller than 3-inch

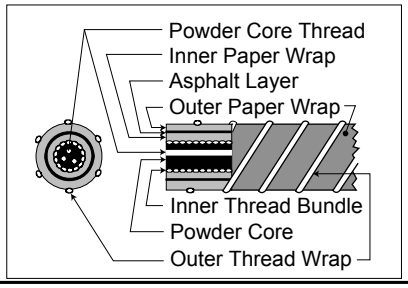
(See Lecture Notes for table of granulation sizes.)

Aerial Shell Firing

- **Video Demonstrations of an aerial shell firing from a mortar. [2 min.]**

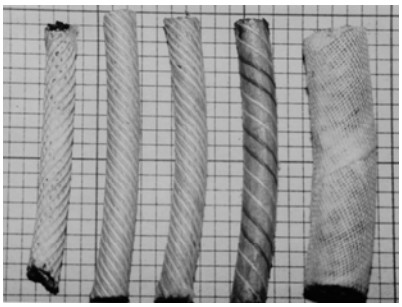
Fireworks Time Fuse

- **Fireworks time fuse is an internally burning fuse, about 1/4 inch in diameter. It burns about 1/3 inch/sec.**



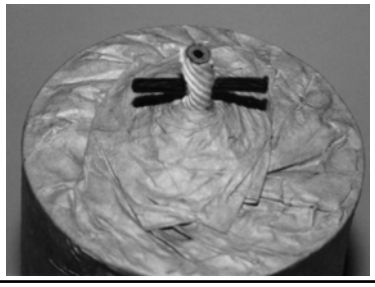
Fireworks Time Fuse

- **Examples of various types of fireworks time fuse.** [0.1 inch (2.5 mm) per division]



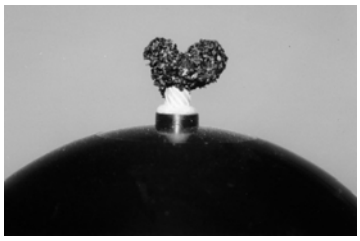
Time Fuse Ignition – Priming

- **In "cross matching", a small hole is punched through the time fuse and a piece of black match is inserted.**



Time Fuse Ignition – Priming

- **Time fuse is coated with prime composition (fine Black Powder mixed with binder) then dipped in granulated Black Powder to increase the likelihood of ignition.**



Firework Stars

- **Stars are pellets of pyrotechnic composition that produce the visual display of colored light, a trail of sparks, or both.**

Firework Stars

- **Examples of stars being loaded into shells. The size and chemical composition of stars determines how long they burn.**

Firework Stars

- Stars are made in a variety of shapes:
  - "Cut stars" are most often cube shaped.
  - "Pressed stars" are most often compacted into cylindrically shaped stars.
  - "Rolled stars" are made in successive layers that build up to be nearly spherical in shape.

Shell Inserts (Components)

- In addition to (or in place of) stars, aerial shells may contain shell inserts.
- Shell inserts are small devices such as:
  - Small salutes (shots, reports or siatenes).
  - Small aerial shells.
  - Whistles.
  - Saxons.
  - Hummers.
- Shells containing inserts (components) are often called "component shells".

Fireworks Burst Charge

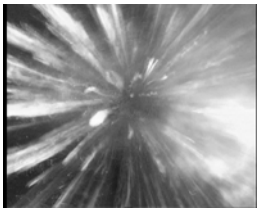
- The charge that bursts an aerial shell is the "burst charge" or "break charge". It is often made by coating pyrotechnic composition on rice hulls ("rice hull powder").

Fireworks Burst Charge

- The coating on rice hull powder can simply be handmade Black Powder but may be a more energetic composition.
- In cylindrical shells, the break charge is often commercial or handmade granular Black Powder.
- The break charge may be placed in the center of a pattern of stars or may simply be mixed in randomly with the stars.

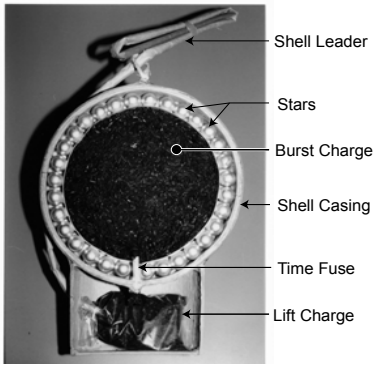
Aerial Shell Bursting

- Video demonstration of the an aerial shell bursting. [1 min.]
- High frame rate video demonstration of an aerial shell bursting. [1 min.]



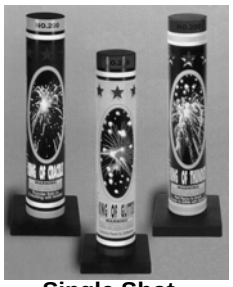
Examples Of Aerial Shell Labels

Model Of a Spherical Aerial Ahell



Consumer Fireworks Aerial Shells

- **Consumer fireworks aerial shells are occasionally used in very small displays.**



Single Shot

Reloadable

End of Unit

Aerial Shell Malfunctions

- Malfunctions, their causes and safety.
  - Premature Ignition
  - Hang Fire
  - Misfire
  - Flowerpot
  - Shell "Detonation" (VIME)
  - Muzzle Break
  - Low Break
  - Dud
- Measures to protect the public and crew.

Malfunctions

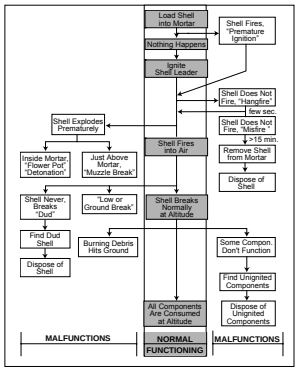
- In this course, a malfunction is defined as hazardous performance, other than intended.
- Some malfunctions can be caused by the manufacturer or by mishandling after manufacturing.
- Some aerial shell problems can be identified by careful inspection at the display site.

Discussion of Malfunctions

- Format for malfunction discussions:
  1. Description (definition) of the malfunction — for the purpose of discussion.
  2. "Cause"— primary cause(s), emphasizing things under the control of the display operator or that might be detected by inspection.
  3. "Prevention"— emphasizing actions that can be taken by the crew (not by the mfg.) .
  4. "If it happens" — what can be done to help minimize consequences of this malfunction.

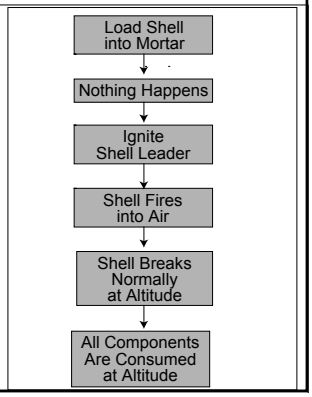
Proper Functioning vs Malfunctions

- A flow chart for shell firing sequence will be used in this discussion.
- Proper functioning (center) and possible malfunctions (to either side).



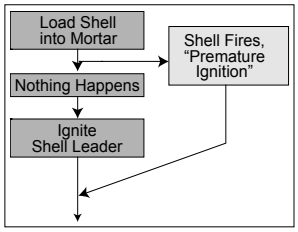
Proper Functioning

- The sequence of events for an aerial shell that functions properly.



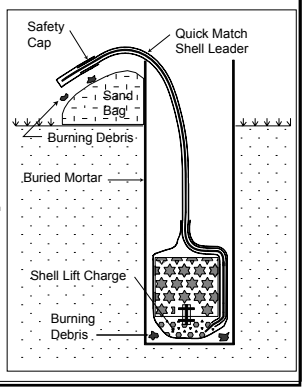
Premature Ignition

- An aerial shell fires from mortar before it is intentionally ignited.



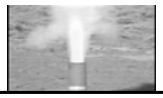
Premature Ignition

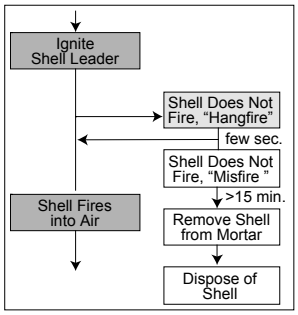
- **Cause: Burning debris in mortar or on ground, or sparks.**
- **Prevention: Eliminate burning debris and exposed composition.**
- **If it happens: NEVER have body parts over a loaded mortar ! ! !**



Hang Fire

- **An unusually long delay (more than a few seconds) between lighting the shell leader and its firing.**
- **Short [V-1 m]**
- **Med. [V-1 m]**



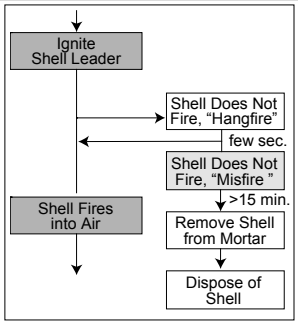


Hang Fire

- **Cause: Shell leader (fuse) damaged or damp.**
- **Prevention: Careful inspection of shells and protection of the shells from moisture may reduce the probability.**
- **If it happens: Wait several seconds before approaching to mark the mortar; be aware that the aerial shell may fire at any time. Also verbally warn the crew not to reload the mortar.**

Misfire

- **The shell leader is ignited, but the aerial shell never fires from the mortar.**

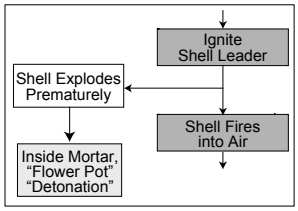


Misfire

- **Cause: Shell leader damaged or damp.**
- **Prevention: Careful inspection of shells and protection of the shells from moisture may reduce the probability.**
- **If it happens: Initially treat it as a Hang Fire. After the display, but at least after 15 minutes, spray water into the mortar, wait at least 5 more minutes and carefully remove the shell from the mortar.**

Flowerpot

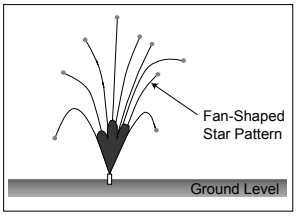
- **A shell explodes relatively weakly while inside the mortar, which usually remains intact.**



- **Flowerpot [Video - 1 m]**

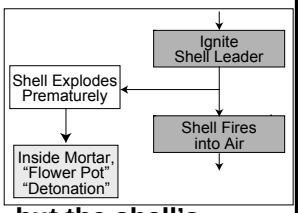
Flowerpot

- Cause: A major fire leak into the shell. Possibly because of a total failure of the shell casing.
- Prevention: Inspection might possibly find shell casing damage.
- If it happens: Protect shells from sparks and burning debris, wear proper clothing and personal protection equipment.



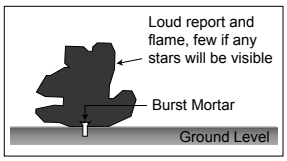
Shell "Detonation"

- A shell explodes violently while still in the mortar, which is often destroyed. [Almost certainly not a true high explosive detonation, but the shell's contents are consumed almost instantly.]
- Shell "Detonation" [Video 1 min.]



Shell "Detonation"

- Cause: A major fire leak into a star shell. (Why not flowerpot? Not established.) A minor fire leak into a salute, will result in a violent explosion.
- Prevention: In extreme cases, aerial shell inspection may reveal damage to the shell casing.



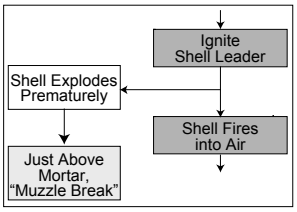
Shell "Detonation"

- If it happens: No time to react. Have well buried or barricaded mortars, have personnel in a "protective position", have personal protection equipment being worn, and inspect for damage.

Muzzle Break

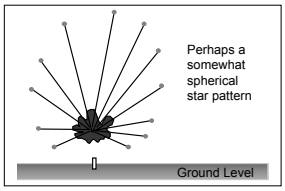
- A shell explodes just after leaving the mortar.
- Muzzle Break

[Video 1 min.]



Muzzle Break

- Cause: A relatively minor fire leak into a star shell or an internal ignition due to friction from the movement of stars inside the shell. This malfunction seems to be more common with shells larger than 6 inch.

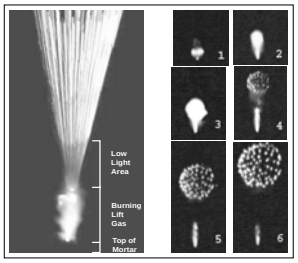


Muzzle Break

- **Prevention: None known. The point where the minor fire leak most likely occurs (around the time fuses) is not exposed to view.**
- **If it happens: There is no time to react. Have unloaded fireworks well protected, have personnel in a "protective position" (crouched down and facing away from the mortar) and have personal protection equipment being worn.**

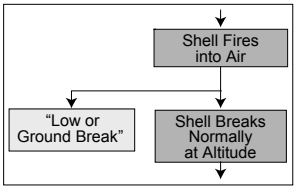
Muzzle Break/Flowerpot Appearance

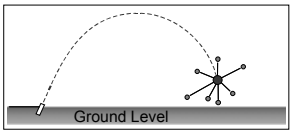
- **When a muzzle breaking shell is traveling upward at a high speed, it creates the visual appearance of a flower pot.**
- **The two views are of the same event. On the left as seen by an observer; on the right as seen with a high frame rate video camera.**



Low (or Ground) Break

- **The aerial shell fires normally, but bursts near or on the ground.**





Low (or Ground) Break

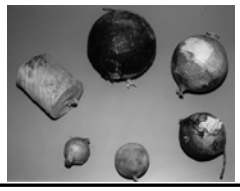
- **Possible Causes:**
  - **Shell fired from over-sized mortar.**
  - **Some lift powder was lost or was quite damp.**
  - **The mortar has a leaking or blown-out plug.**
  - **The shell was not nearly fully lowered into the mortar.**

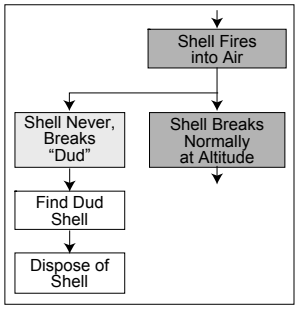
Low (or Ground) Break

- **Prevention:**
  - **Take care in loading (reloading) shells,**
  - **Inspect shells for leaking lift powder and signs of dampness,**
  - **Inspect mortar for well attached plug, and**
  - **Clean mortar (but only when necessary).**
- **If it happens: When possible, have mortars angled away from the crew and spectators, use a large display site, have no combustibles in fallout area, and keep shells protected from burning debris.**

Dud Shell

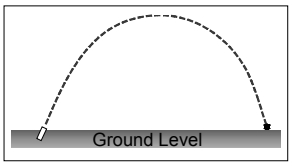
- **The aerial shell fires normally, but never bursts and falls to ground as a "live" (i.e., unexploded) shell.**





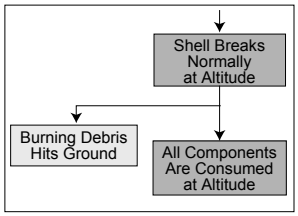
Dud Shell

- Cause: Damp or damaged time fuse or insufficient prime.
- Prevention: Careful shell inspection may find dampness or past water damage.
- If it happens: When possible, have mortars angled away from crew and spectators, use a large display site. Locate and remove the dud shell after the display, and properly dispose of the dud shell.



Burning Fallout

- The shell breaks at altitude, but some burning material falls to the ground.

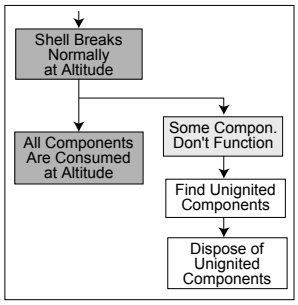


Burning Fallout

- Cause: Stars or components are damp or over-size; non-pyrotechnic materials in the aerial shell ignited when shell burst.
- Prevention: Careful aerial shell inspection for current dampness or past water damage might reveal a problem.
- If it happens: When possible, have mortars angled away from the crew and spectators, use a large display site, have no combustibles in the fallout area.

Dud Components (Inserts)

- Some components (inserts) in shell fail to ignite or burn and fall to the ground as "live" items.



Dud Components (Inserts)

- Cause: Stars or components are damp, are poorly primed, or the shell break is too powerful for the stars or components to remain ignited.
- Prevention: Careful shell inspection for current dampness or water damage might reveal a problem.
- If it happens: When possible, use mortars angled away from crew and spectators, use a large display site. Retrieve unignited components after the display.

Measures To Protect the Public and Crew in Case of Malfunctions

- Over the past 25 years there have been great improvements in the performance of aerial fireworks. However, the display crew must never assume no malfunctions will occur.
- Taking just the first two measures in the list to follow will eliminate the vast majority of injuries to the public.

Measures To Protect the Public and Crew in Case of Malfunctions

- **Prioritized list:**
  - **PROVIDE ADEQUATE SPECTATOR SEPARATION DISTANCE**
  - **LOCATE AND REMOVE DUDS**
  - **Inspect the shells on site well before the display.** (Discussed on slides to follow.)
  - **Provide the crew with proper training and personal protective equipment.** (Discussed in section on equipment.)

Measures To Protect the Public and Crew in Case of Malfunctions

- **Prioritized list (Continued):**
  - **Use strong mortar racks, such that mortars will not be repositioned by a malfunction.** (Discussed in section on equipment.)
  - **Use proper mortar burial and/or barricading.** (Discussed in section on mortar placement.)
  - **Maintain crowd control.**
  - **Take actions to protect fireworks from adverse weather and sparks.**

On-Site Shell Inspections

- **No leaking lift powder. (Loose powder in a box of aerial shells may indicate that a shell(s) is loosing its lift powder.)**

On-Site Shell Inspections

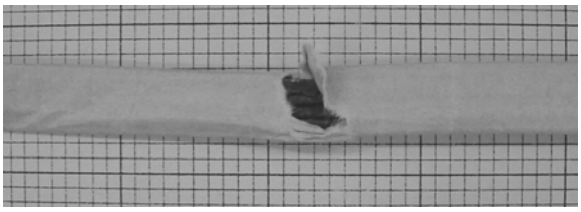
- **The proper fit of shells in mortars (close but freely sliding).**

On-Site Shell Inspections

- **Leader fuse must be secured to the top of the shell. The shell below needs to be repaired (it could be loaded upside down).**

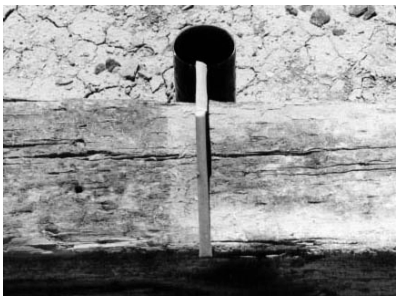
On-Site Shell Inspections

- **No tears or other damage to shell leader (fuse). The leader should be repaired.**



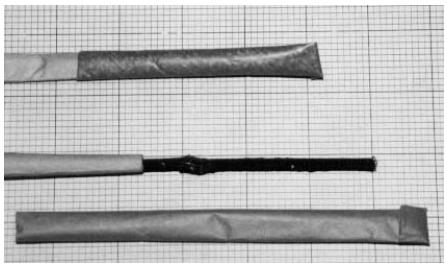
On-Site Shell Inspections

- Leader is long enough (mortar length plus about 6 inches).



On-Site Shell Inspections

- The black match delay element is long enough (usually 3 to 4 inches), and the safety cap is present and in place.

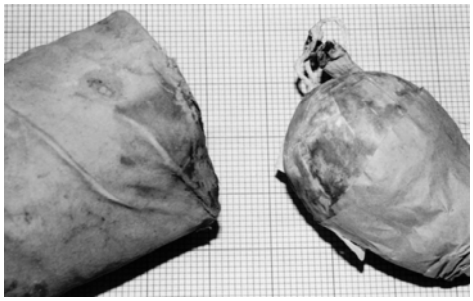


On-Site Shell Inspections

- A strong lowering cord is present on large aerial shells (≧8-inch).

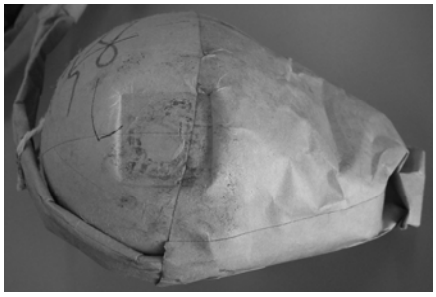
On-Site Shell Inspections

- No evidence of water damage or of aerial shell having been wet.



On-Site Shell Inspections

- No dented, broken or cracked aerial shell casings.



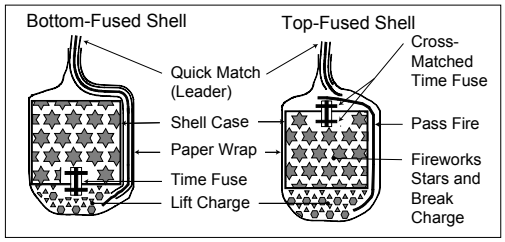
End of Unit

Alternate Shell Construction

- Alternate aerial shell fusing
- Other aerial shell types
- Spherical aerial shell star and burst charge configurations
- Cylindrical shell burst configurations
- Star types
- Electric matches and connectors
- Other ignition systems

Top Fused Aerial Shells

- Top-fused shells have their time fuse installed on top of the shell (as oriented when in the mortar). A "passfire" fuse carries fire down to the lift charge.



Top Fused Aerial Shells

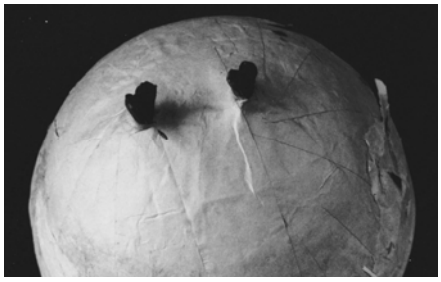
- Top-fused aerial shells are less likely to experience fire leaks around the time fuse. Top fusing is most often used on cylindrical shells that are large or multi-break.
- With top-fused aerial shells, there is the possibility of the time fuse igniting but not the lift charge. This will cause the shell to explode at the bottom of the mortar after a few seconds delay.

Redundant Time Fuses

- The time fuse on a shell occasionally fails to initially ignite, to burn completely, or to successfully transfer fire to the contents of the shell. When that happens on a shell with a single time fuse, it will fail to explode and will fall to the ground as a dud (or possibly ignite on impact).
- Time fuses are generally cross-matched or primed to reduce the chance of their ignition failure.

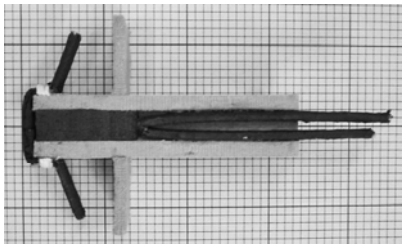
Redundant Time Fuses

- It is common to use a second (or even third) time fuse on shells, to greatly reduce the number of time fuse failures.



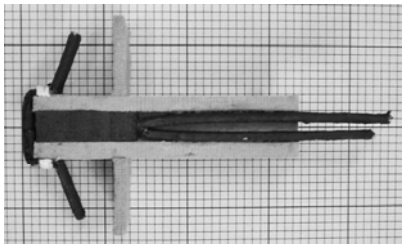
Spolette Fuses

- A spolette is a handmade fuse in which Black Powder is tightly compacted in a strong tube with a relatively small internal diameter, typically about 3/8 inch.



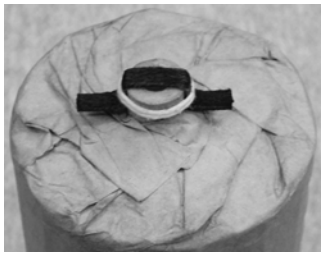
Spolette Fuses

- Properly made spolettes are highly reliable, when they have black match across one end and multiple pieces inserted in the open end of the tube.



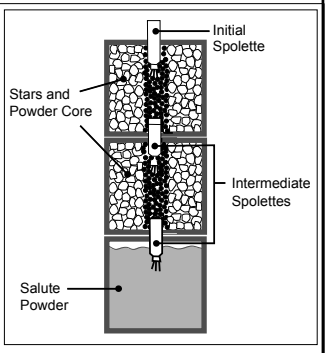
Spolette Fuses

- Spolettes are preferred when the burn time must be short or for precise timing.
- Spolettes are used in a top-fused configuration, usually on large caliber and multi-break cylindrical aerial shells.



Multi-Break Shells

- In essence, a multi-break shell is a stacked collection of individual shells, typically with each break igniting the delay element for the next break.



Multi-Break Shells

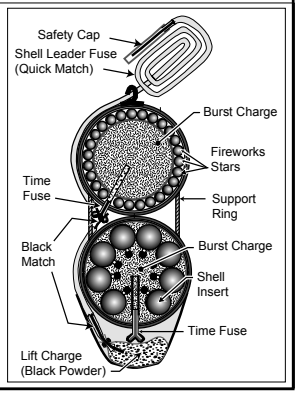
- With multi-break shells, all the possible shell malfunctions are either more likely to occur or the consequences are more serious if a malfunction does occur, for example:
  - They generally contain a greater quantity of pyrotechnic material than single-break shells.
  - There is a chance that one or more of the breaks will explode close to the ground or will fall to the ground as a dud.

Multi-Break Shells

- Multi-break shells can range to very large sizes. This is a photo of a 12-inch 3-break shell.
- The firing of multi-break shells often requires the use of special mortars (i.e., ones with extra strength and length).

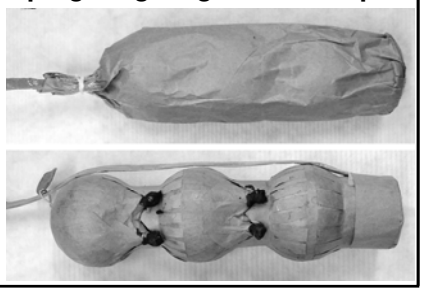
Multi-Break Shells

- Recently spherical, multi-break shells have begun to be used, sometimes called “Peanut” or “Double-Bubble” shells. The two single-break shells are connected by a support ring between them.



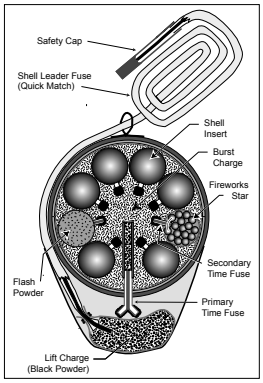
Multi-Break Shells

- A 3-inch, 3-break spherical shell. Note the support rings between the shells, and that only the escaping lift gas ignites the top two shells.



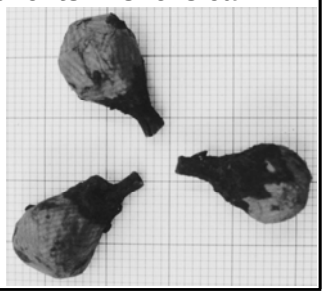
Component Shells

- Component shells have multiple internally-fused devices or shells that are ignited as the main shell's burst charge is burning. (These shells may contain stars in addition to components.)



Component Shells

- If all the components are shells themselves, the shell will be called a "shell of shells". The components in shells can have a variety of shapes and sizes, and may be called shell inserts.

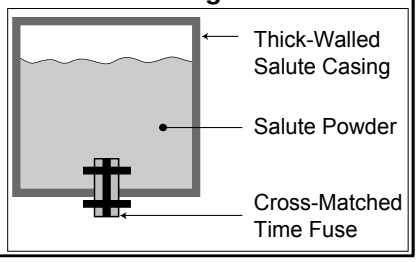


Component Shells

- Dud components may be small, but can be powerful enough to cause serious injuries if found and ignited. It is important that dud components be located and disposed of after a display.
- It will often be difficult to determine whether the components have functioned. Often it is necessary to inspect them carefully.

Salutes (Also Reports or Maroons)

- Salutes contain salute powder and produce a loud report when they explode. The salute powder will generally be a flash powder, in which case a bright flash of light is also produced and may contain titanium for white sparks.



Salutes (Also Reports or Maroons)

- Aerial salute maximums (NFPA-1123) are:
  - Maximum single-break salute size, with limited firing restrictions, is 3 inch.
  - Maximum single-break salute size, with greater firing restrictions, is 5 inch.
  - Maximum multi-break bottom-shot size is 5 inch.
  - Maximum component salute size is 3 inch and 3 ounces.

Salutes (Also Reports or Maroons)

- **Aerial salute firing and use restrictions for ALL single-break salutes:**
  - **They must be fired from non-metal mortars.**
  - **They must be fired remotely or with an additional 5-second delay on the leader fuse.**
  - **They must be pre-loaded into mortars.**

Salutes (Also Reports or Maroons)

- **Aerial salute firing and use restrictions for single-break salutes >3 to 5 inch:**
  - **All the above requirements for salutes must be met.**
  - **Mortars must be individually supported and separated from others by 10 times their diameter.**
  - **They must only be used by licensed display operators or companies.**

Salutes (Also Reports or Maroons)

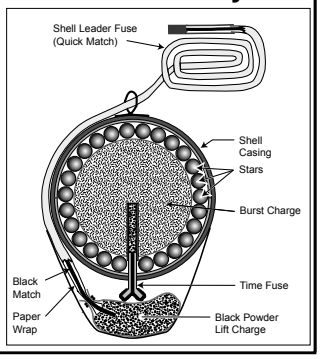
- **Aerial salute firing and use restrictions for multi-break shells containing salutes:**
  - **All the requirements for salutes greater than 3 inch must be meet except that steel mortars are permitted.**
  - **Only the bottom shot can exceed 3 inches and must not exceed 5 inches in size.**

Star and Burst Charge Configurations

- **When fireworks stars and the break charge are randomly mixed inside an aerial shell, a random pattern of stars will be formed when the shell bursts.**

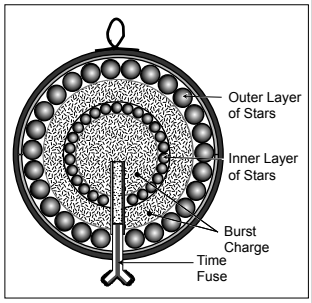
Star and Burst Charge Configurations

- **When the fireworks stars are carefully positioned around a central burst charge, the pattern of stars produced when the shell bursts will be similar to that of the stars inside the shell.**



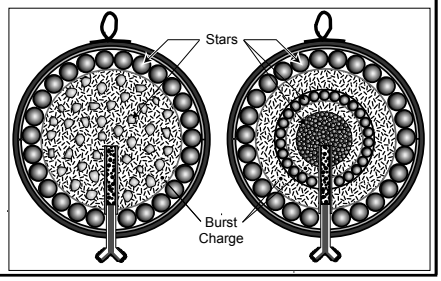
Star and Burst Charge Configurations

- **A common variation to the single hollow spherical pattern are those with inner star petals. These shells burst to appear as a hollow spherical star pattern inside a larger outer hollow spherical star pattern.**



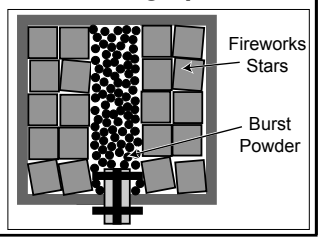
Star and Burst Charge Configurations

- **A dense collection of stars appearing at the center of a spherical pattern of stars is called a "heart", one with randomly placed stars is described as having "pistils".**



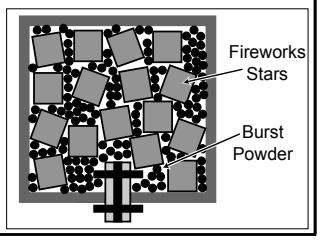
Star and Burst Charge Configurations

- **Cylindrical shells also have varied star and burst charge configurations.**
- **Often cylindrical aerial shells use a central core filled with granulated rough powder (hand-made Black Powder). Such shells produce a some-what symmetric spread of burning stars.**



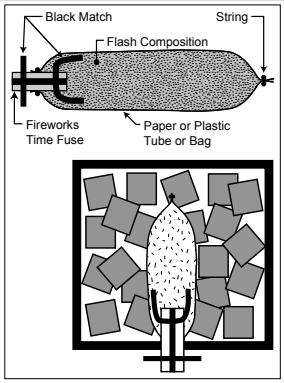
Star and Burst Charge Configurations

- **If the burst charge is distributed uniformly throughout the interior of a shell, then it produces a random spread of stars.**
- **The burst charge may also be commercial Black Powder (gun powder), hand made powder or a combination of different powders.**



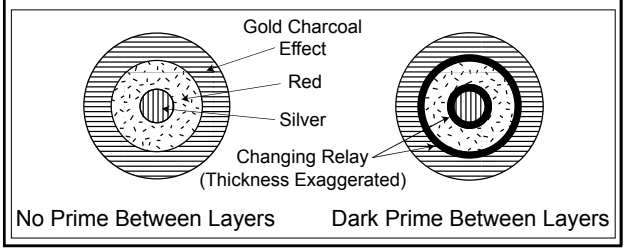
Star and Burst Charge Configurations

- **A small central charge of a more powerfully exploding composition in a thin-walled tube (called a flash bag) can be used.**



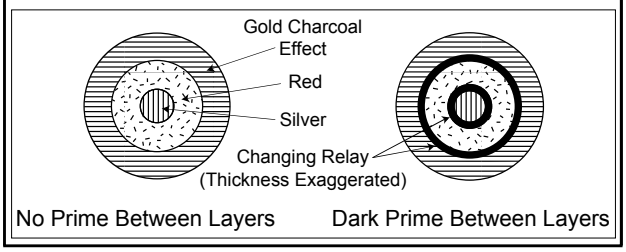
Star Types – Color Changing

- **Color-changing stars, commonly used in large spherical shells, are made by layering different chemical compositions to form the complete star.**



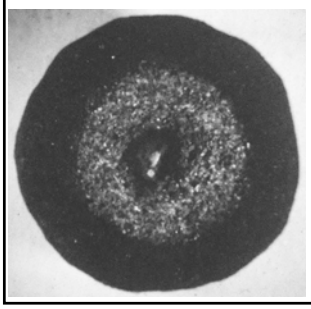
Star Types – Color Changing

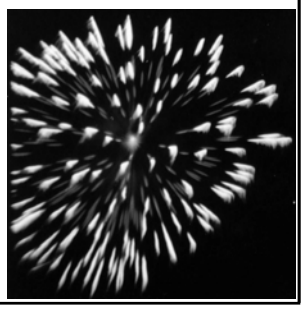
- **In exhibition quality shells, the color-changing stars will use a "dark prime" or "changing relay" to aid in the appearance of a perfectly timed color change.**



Star Types – Color Changing

- Color change star (without dark prime, left); color change shell burst (right).



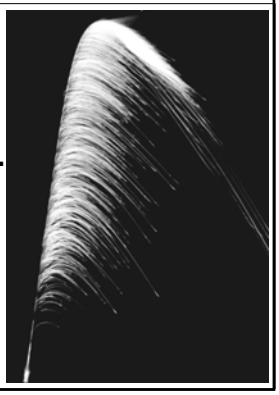


Star Types

- When the first (or only) star effect is one that produces a trail of sparks, the spherical aerial shell is generally referred to as a "Chrysanthemum". If the first star effect is a color without a trail of sparks, the shell is generally referred to as a "Peony". When the outer prime layer is especially thick and produces orange sparks, the shell description usually includes the term "Reddish Gamboge".

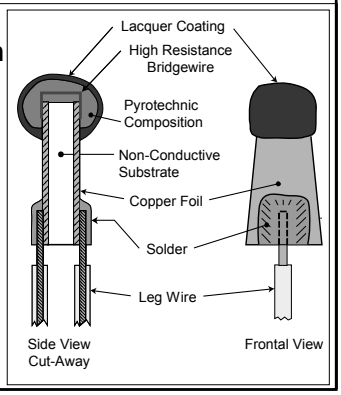
Star Types – Comet and Strobe

- Comet stars produce long-lasting trails of sparks as they burn, ranging from dim orange to bright white.
- Strobe stars are stars that produce bright flashes of colored light separated by brief periods of darkness.



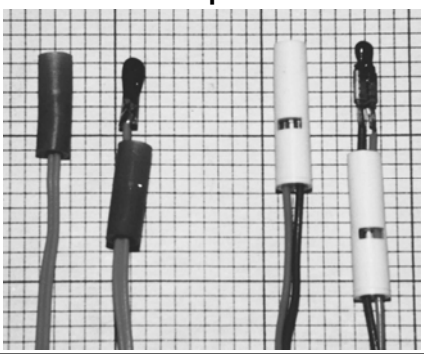
Electric Matches

- An electric match consists of a high resistance bridge wire surrounded by heat sensitive composition. An electric current heats the bridge wire and ignites composition to produce a small burst of fire.



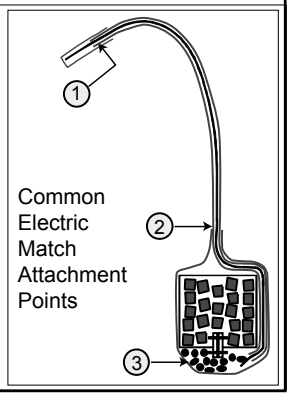
Electric Matches

- Electric match examples.



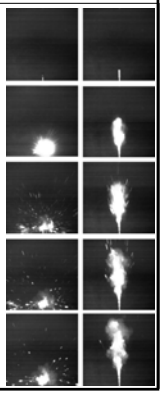
Electric Matche Attachment Points

- Electric matches may be installed at any point along the ignition train of an aerial shell, but three places are most common.



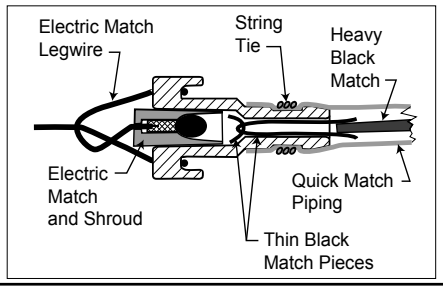
Electric Match - Shrouds

- Two sets of images of electric matches firing, each 0.001 s apart in time. On the left is an un-shrouded match firing, which is not well directed. On the right is a shrouded match, which is well directed, is more intense and lasts longer.
- For safety and performance, ALWAYS keep shrouds in place.



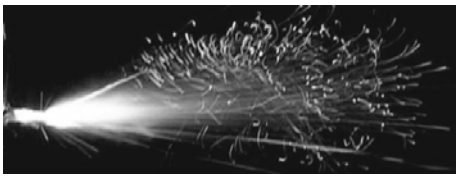
Electric Match - Connector

- This connector reduces the chances of an accidental ignition because it leaves the safety shroud in place.



Electric Match - Connector

- A connector attached to quick match and the firing of an e-match in a connector.

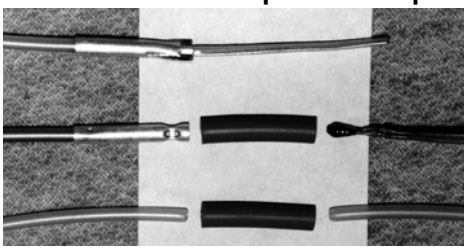


Shock-Tube Ignition Systems

- In the 1990s a shock-tube system (No Match™) was introduced and showed some promise. However, problems with cost and availability have generally limited its use.
  - Shock tube is 1/8-inch in diameter and has a propagation rate of 6000 ft/s.
  - Shock tube can be spliced or split using inert tubing and plastic tees.

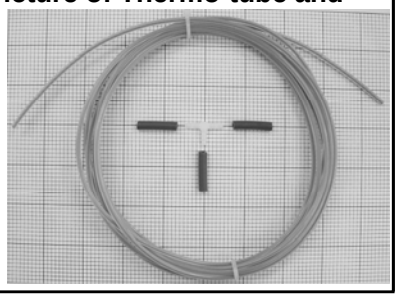
Shock-Tube Ignition Systems

- Shock tube requires a flame-to-shock converter for its ignition by a fuse or electric match. These are the thin metal tubes shown in the top two examples.



Thermo-Tube Ignition Systems

- A new product with great potential (Lightning Thermo-Tube™) has been introduced. Picture of Thermo-tube and components for splicing and splitting it.

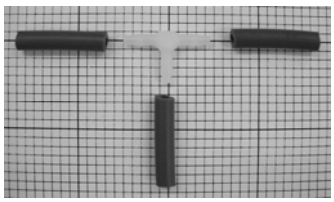


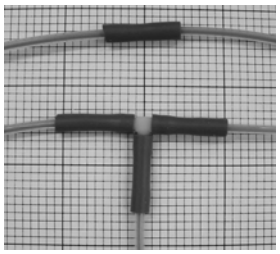
Thermo-Tube Ignition Systems

- **Thermo-Tube:**
  - **Has a propagation rate of ~3700 ft/s.**
  - **Can be initiated directly by coupling to an electric match.**
  - **Can be used directly to ignite visco fuse, aerial shell leaders, Black Powder, etc.**
  - **Can be spliced or split using inert tubing and plastic tees.**

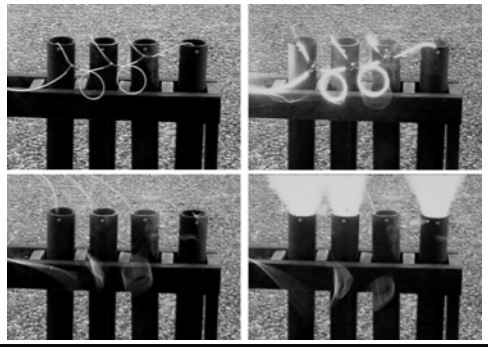
Thermo-Tube Ignition Systems

- **Examples of inert tubing and plastic tees used for coupling and splitting shock and Thermo-Tube.**





- **Shock-tube firing example.**



End of Unit

Typical Aerial Shell Performance

- Aerial shell and mortar parameters
- Aerial shell firing time sequence
- Mortar pressures and recoil forces
- Muzzle velocity and burst height
- Effect of mortar length
- Burst delay time and burst diameter
- Explosive and thermal output
- Mortar tilt angle and drift distance
- Aerial shell float time in water

Typical Shell and Mortar Parameters

- Typical spherical aerial shells:

Shell Size (in.)	Shell Diam. (in.)	Shell Weight (lb.)	Lift Powder Type	Lift Weight (oz)	Dead Volume (cu. in.)	Mortar Length (in.)
3	2.7	0.3	4–5 FA	0.5	12	20
4	3.7	0.8	4–5 FA	1.0	24	24
5	4.7	1.5	4 FA	1.7	46	30
6	5.6	2.5	4 FA	2.7	72	36
8	7.6	5.5	4 FA	5.5	150	42
10	9.5	11.	4 FA	10.	290	48
12	11.5	18.	4 FA	17.	520	54

Typical Shell and Mortar Parameters

- Typical cylindrical aerial shells:

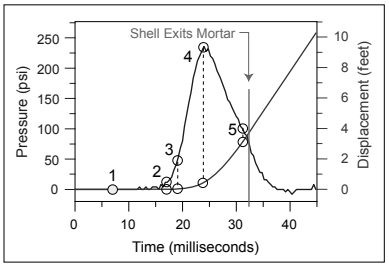
Shell Size (in.)	Shell Diam. (in.)	Shell Weight (lb.)	Lift Powder Type	Lift Weight (oz)	Dead Volume (cu. in.)	Mortar Length (in.)
3	2.7	0.4	2–3 FA	1.0	9	20
4	3.7	1.0	2–3 FA	1.9	20	24
5	4.7	2.0	2 FA	3.0	35	30
6	5.6	4.0	2 FA	4.5	57	36
8	7.6	10.	2 FA	9.0	121	42
10	9.5	20.	2 FA	16.	234	48
12	11.5	36.	2 FA	26.	394	54

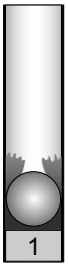
Aerial Shell Firing Time Sequence

- The general shape of typical mortar pressure profiles and the overall time for aerial shells to exit the mortar are mostly independent of shell size.
- The data that follow are for an 8-inch spherical shell. The points numbered in the graphs to follow correspond to those in the accompanying shell firing illustrations.

Aerial Shell Firing Time Sequence

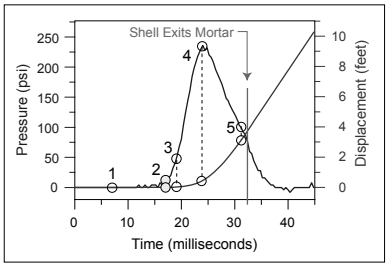
- About 0.007 second after the ignition of the lift the flame has spread through the lift charge slightly past the top of the shell.





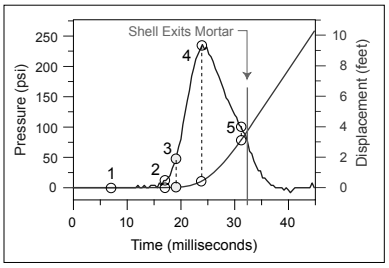
Aerial Shell Firing Time Sequence

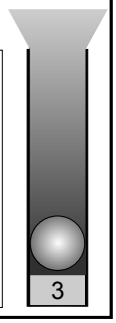
- After another 0.010 second the flame can be seen to start exiting the top of the mortar.



Aerial Shell Firing Time Sequence

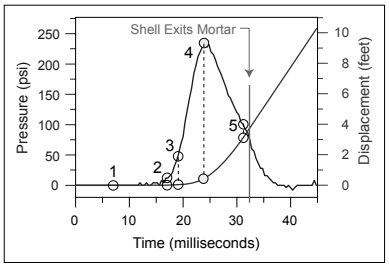
- **After another 0.002 second the pressure rose to where the upward lift force on the shell equaled gravitational force.**

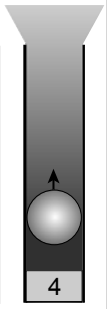




Aerial Shell Firing Time Sequence

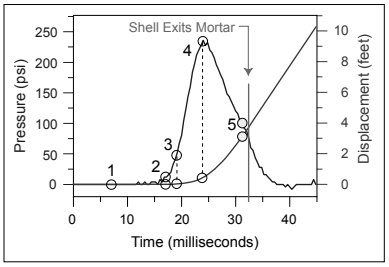
- **After another 0.005 sec. the pressure rose to its maximum and the shell rose to about 12% of the distance up the mortar.**

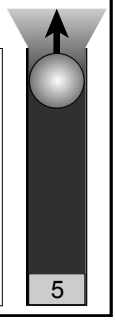




Aerial Shell Firing Time Sequence

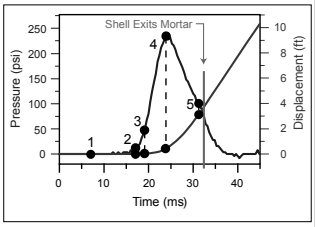
- **After another 0.007 sec. the shell rose to nearly the top of the mortar and the mortar pressure dropped significantly.**





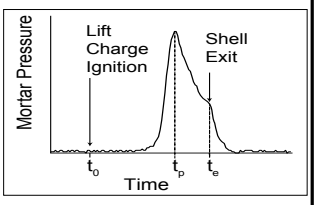
Aerial Shell Firing Time Sequence

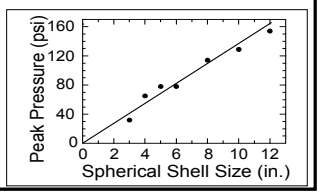
- **After another 0.002 second the aerial shell exited the mortar.** (Not shown.)
- **The time for this shell to exit the mortar was 0.032 second. Typical shell exit times range from 0.03 to 0.06 second.**



Internal Mortar Pressures

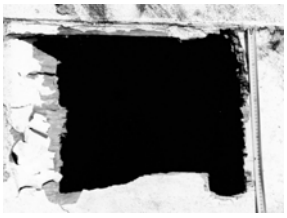
- **Graph is typical of mortar pressure during firing of an aerial shell.**
- **Graph is typical of peak pressures for spherical shells (136 trials).**
  - **Average peak is 14 psi / shell inch**





Mortar Recoil Forces

- **When aerial shells are fired from mortars, the mortar will recoil as a result.**
  - **If the mortar is positioned on a support structure, it is important that the structure has sufficient strength.**



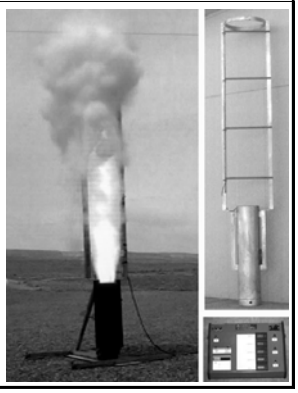
Mortar Recoil Forces

- **Approximate peak mortar recoil forces when firing typical spherical aerial shells.**

Mortar Size [ID] (in.)	Peak Recoil Force (lbf)[a]	Average Recoil Force (lbf) [b]	Recoil Impulse (lbf·s) [c]
3.0	290	130	3.3
4.0	700	320	7.9
5.0	1,400	630	16
6.0	2,300	1000	26
8.0	5,300	2400	60
10.0	11,000	5000	120
12.0	18,000	8000	200

Aerial Shell Muzzle Velocity

- **Typical spherical shells leave the mortar traveling about 300 ft/s, which is about 200 mph.**

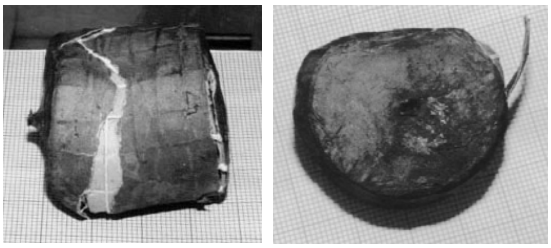


Aerial Shell Muzzle Velocity

- **The reason large caliber shells travel to greater heights is not because they start out traveling faster. It is because their greater mass allows them to better resist aerodynamic drag forces acting on them.**

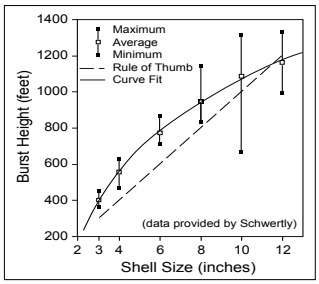
Aerial Shell Muzzle Velocity

- **A shell falling to the ground after reaching its full height will be traveling about 120 ft/s or 80 mph for large shells and about 90 ft/s or 60 mph for small shells.**



Aerial Shell Burst Height

- **A useful "rule of thumb" for burst height of spherical shells is that they reach 100 feet of height per inch of shell size.**
- **However, for mid-sized shells, this tends to under estimate typical shell burst height by about 150 feet.**
- [At +1000 ft. MSL]

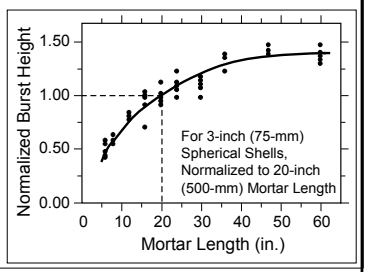


Aerial Shell Burst Height

- **Many factors affect the burst height of individual aerial shells:**
  - **Delay fuse timing**
  - **Lift powder effectiveness**
  - **Lift powder moisture and temperature**
  - **Mortar length and tilt angle**
  - **Clearance between shell and mortar-wall**
  - **Dead volume below the aerial shell**
  - **Shell weight and shape**

Effect of Mortar Length

- As mortars are made longer, aerial shells fired from them reach higher altitudes. This is a result of the greater muzzle velocity reached by the shell before it exits the mortar.



Effect of Mortar Length

- Note that the effectiveness of additional mortar length decreased as mortar length got progressively longer.
- Generally, small caliber mortars (< 8 inch) are made at least 5 times as long as their internal diameter. Larger mortars (≥ 8 inch) are usually only at least 4 times as long as their internal diameter.

Aerial Shell Burst Delay Times

- The average time between firing a shell and when it breaks depends on shell size. Approximate burst delay times for spherical shells are:

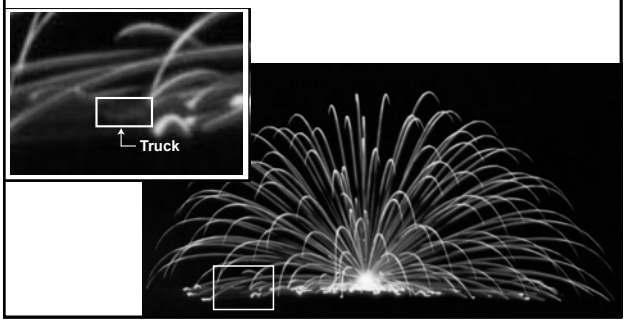
Shell Size (in.)	Shell Size (mm)	Approx. Delay Time (s)
2.5	62	2.5
3	75	3
4	100	3.5
5	125	4
6	150	5
8	200	6
10	250	6.5
12	300	7

Aerial Shell Burst Delay Times

- In designing a display synchronized to music, it is necessary to know the precise delay time for each type of shell, to know how much in advance to fire the shells so they burst on cue to fit the music.
- The typical time taken for an aerial shell to explode, after its contents are ignited, ranges from approximately 0.04 second for a 3-inch shell to roughly 0.10 second for a 12-inch shell.

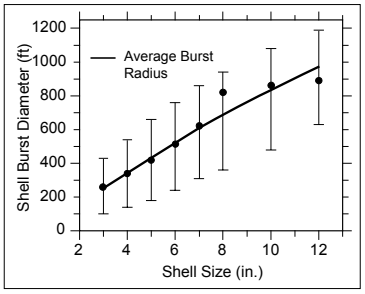
Aerial Shell Burst Spreads

- Photo of the 800-foot burst spread for a high quality 8-inch spherical aerial shell.



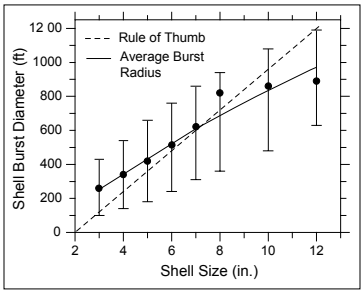
Aerial Shell Burst Spreads

- Large aerial shells generally burst with greater force than do small shells. Also, because their stars are more massive, large shells typically have a wider spread.



Aerial Shell Burst Spreads

- A somewhat reasonable "rule-of-thumb" is that shells burst with a diameter of about 100 feet per shell inch, this is the dashed line on the graph.

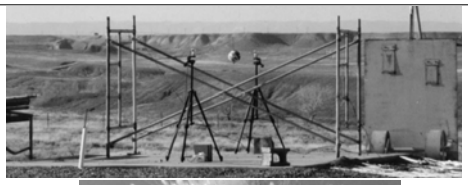


Aerial Shell Burst Spreads

- Star spread results as a table:

Spherical Shell Size		Typical Spread of Stars (diameter)	
(in.)	(mm)	(ft)	(m)
3	75	260	79
4	100	340	103
5	125	420	143
6	150	510	155
8	200	820	248
10	250	860	260
12	300	890	270

Explosive Output from Fireworks



Explosive Output from Fireworks

- Free field salute blast pressures (at 4 ft.):

Salute Shell Size (in.)	Peak Blast Pressure (psi)	Air Blast TNT Equivalent (oz)
1	4	0.5
3	7	1
4	10	2

  – Ear drum rupture threshold = about 3 psi.

- The flame temperatures produced by exploding fireworks salutes typically exceed 3000 ºC (6000 ºF).

Explosive Output from Fireworks

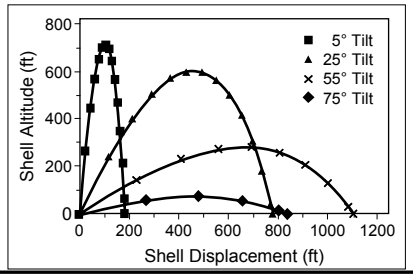
- Star shell blast pressures (at 4 ft.):

Star Shell Size (in.)	Peak Blast Pressure (psi)	Max. Star Spread (ft)
5	1.3	380
8	6	470
10	13	510

- The flame temperatures produced by burning fireworks stars often exceed 2000 °C (4000 °F).

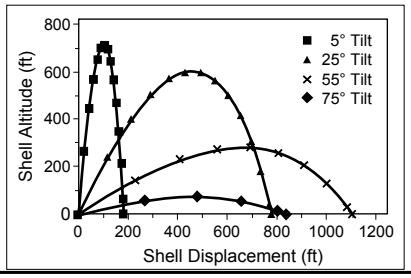
"Dud" Aerial Shell Trajectory

- The graph illustrates the trajectory of typical 6-inch dud spherical shells fired from variously tilted mortars.



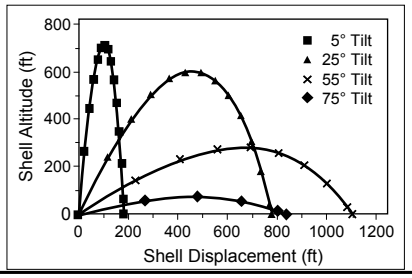
"Dud" Aerial Shell Trajectory

- **Each point corresponds to one second of flight; 6-inch shells typically burst after approximately 5 seconds of flight.**



"Dud" Aerial Shell Trajectory

- **If the shell is a dud (fails to explode in the air), the mortar tilt angle producing the greatest down-range projection is 55°.**



"Dud" Aerial Shell Displacement

- **In the absence of wind, the down-range displacement of typical dud shell landing points for various mortar tilt angles are:**

Tilt Angle	Shell Size and Displacement (ft.)		
	3 in.	6 in.	12 in.
0°	0	0	0
2°	40	70	130
5°	100	180	310
10°	200	360	610
15°	290	520	880
20°	370	660	1130

"Dud" Aerial Shell Displacement

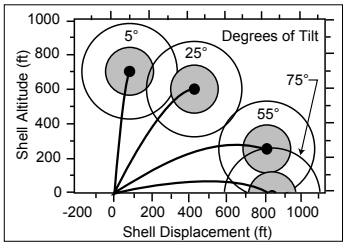
- **In the absence of wind, mortars that are offset by 1/3 the distance from the center of the display site toward the main spectator area, with a tilt angle of about 8° from vertical will cause the average dud shell point-of-fall to be 1/3 the distance beyond the center of the display site.**
  - **This is the maximum mortar displacement allowed by NFPA for angled mortars.**

Aerial Shell Trajectory

- **The delay provided by the time fuse is usually selected to allow the aerial shell to nearly reach its maximum height (apogee) so that it will have almost stopped rising when the shell bursts.**
- **When an aerial shell fires from a tipped mortar and explodes after the normal fuse burn time. There may be the potential for people to be injured.**

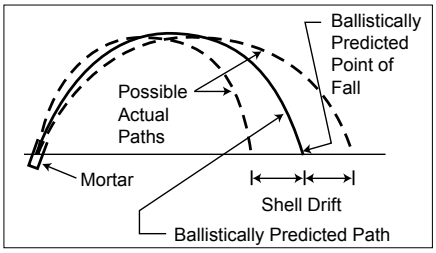
Aerial Shell Trajectory

- **For typical 6-inch spherical shells, the small black circle is the zone of greatest danger, the shaded and unshaded circles represent zones of lesser danger.**



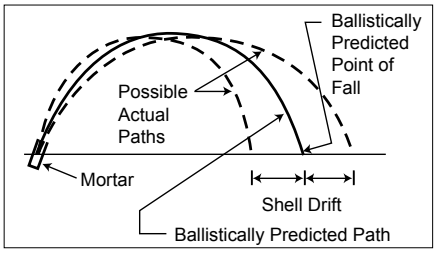
Aerial Shell Drift

- **Because of randomly oriented forces acting on shells, they do not follow their precise ballistically predicted path.**



Aerial Shell Drift

- **Shell drift distance is the difference between the ballistically predicted and actual point-of-fall for dud shells.**



Aerial Shell Drift

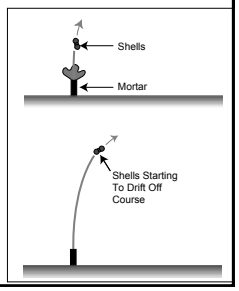
- **Average aerial shell drift distances are:**

Shell Type	Average Drift Distance
Spherical	32 ft/shell in.
Cylindrical	20 ft/shell in.

- **IMPORTANT NOTE: Aerial shells will sometimes drift 2 or 3 times these averages!**

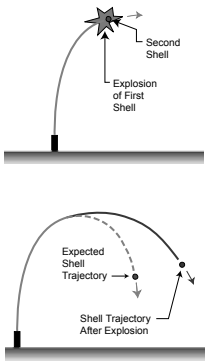
Drift Distance For Multi-break Shells

- **Drift distance for multi-break shells can be greater than single-break shells. Consider the following sequence of events:**
  - **A double-break spherical aerial shell has just fired from the mortar.**
  - **Normal drift factors result in some degree of shell drift for the pair of shells.**



Drift Distance For Multi-break Shells

- **The first shell explodes applying an added force on the second shell, which can push that shell further off course.**
- **Second shell continues to drift, possibly even further off course.**

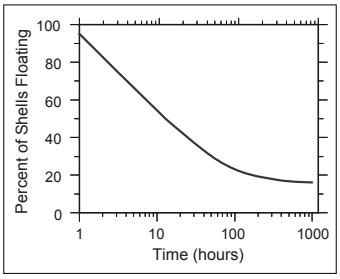


Aerial Shell Float Time In Water

- **When fireworks are discharged from barges or are fired over water from the shore, any dud shells are likely to fall into the water:**
  - **Almost all dud shells landing in water will float, at least for some initial period of time.**
  - **However, only a small percentage of the shell's volume (typically less than 40%) will extend above the surface of the water.**

Aerial Shell Float Time In Water

- **Almost all dud shells will eventually sink, but this may take a very long time.**
- **The pyrotechnic content of floating shells remains viable or becomes viable again after minimal drying.**



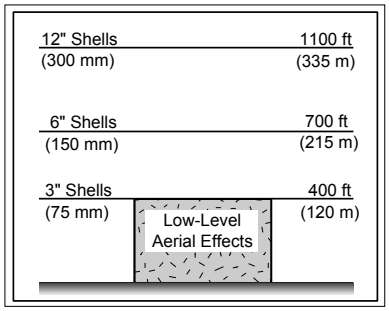
End of Unit

Other Firework Types

- Low-level aerial fireworks
- Firework rockets
- Helicopters
- Wheels
- Fountains, gerbs, and waterfalls
- Lancework
- Fire rope

Low-Level Aerial Fireworks

- Low-level aerial fireworks generally do not reach heights exceeding 400 feet.

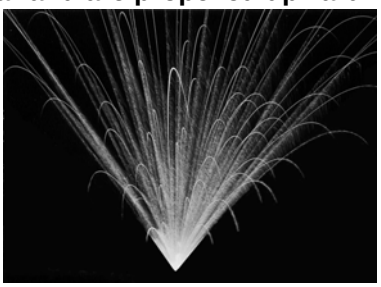


Low-Level Aerial Fireworks

- Low-level aerial fireworks consist of mines, comets, Roman candles, cakes and multi-shot devices. Also included may be small aerial shells (< 2.5 inches).
- Mines, comets and most Roman candles begin their display at ground level. When spectators can view this area of the sky, these items can be quite effective because they fill a portion of the sky that is mostly left blank during the display.

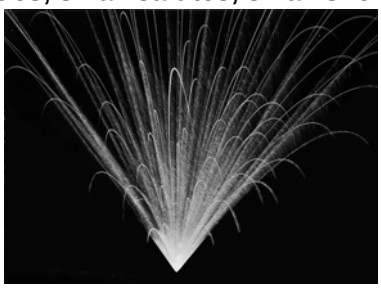
Firework Mine Effect

- A firework mine produces a rising effect in which the materials are ignited in the mortar and are propelled upward.



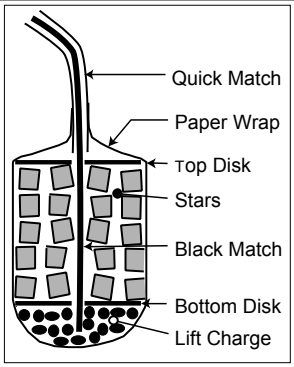
Firework Mine Effect

- Mines often consist only of stars but may also contain component devices (e.g., whistles, small salutes, small shells, etc.).



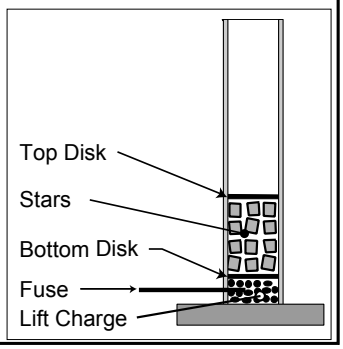
Firework Mine Effect - Large

- Larger mines are generally supplied as a mine shell (or mine “bag”) ready for loading into a normal firework mortar.



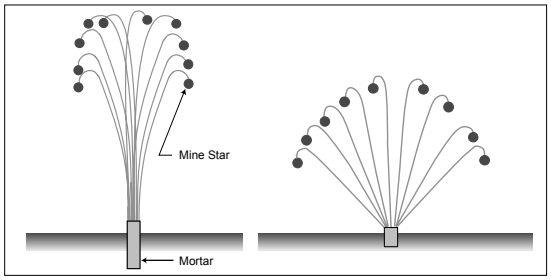
Firework Mine Effect - Small

- **Most small mines (less than 2.5 inches) are supplied as a unit, already loaded into their firing mortar.**



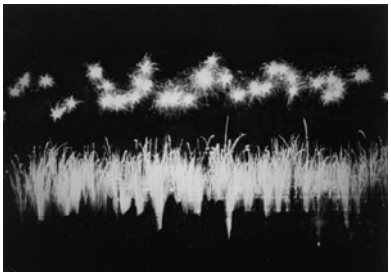
Firework Mine Appearance

- **The appearance of a star mine depends on many factors including mortar length (left – long mortar, right – short mortar).**



Firework Mine Front

- **A mine "front" with stars and small component shells that burst above the display of burning stars (viewed from a distance).**



Firework Mine Characteristics

- **Mine shells appear much like an aerial shell but may feel somewhat soft because of the lack of a substantial shell casing.**
- **Mine shells are fired from mortars, using the same procedure as for aerial shells.**
  - **Mine shells have a potential for fallout of burning debris near the mortar much like aerial shell flowerpot malfunctions. Thus, it is important to guard against accidental ignition of fireworks in the immediate area where mines will be fired.**

Firework Mine Characteristics

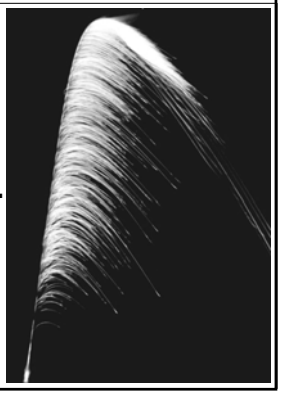
- **The most common sizes for display firework mines are 3 and 4 inch.**
- **Most commonly, mines will not be propelled to the same height as aerial shells of the same size. This is because the relatively low mass of the individual projectiles causes them to slow more quickly due to aerodynamic drag forces.**

Firework Mine Malfunctions

- **Mine shells suffer many of the same malfunctions as aerial shells:**
  - **Burning fallout – accidental ignitions**
  - **Hangfire or Misfire – abandon use of mortar and clear after display**
  - **Shell "Detonations – bury or barricade mortar**
  - **Dud components – locate and dispose**

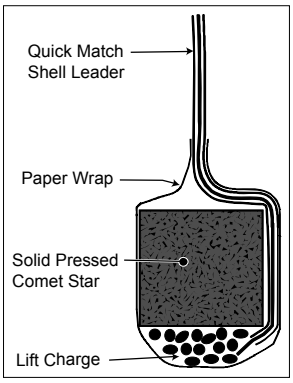
Firework Comet Effect

- A comet produces a rising effect in which a single large pellet of composition is ignited in the mortar and propelled upward. The burning comet generally leaves a trail of rising sparks but may only produce colored light.



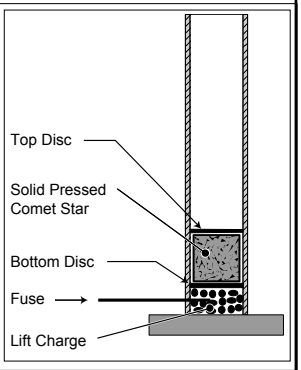
Firework Comet Effect

- Larger caliber comets are typically supplied as comet shells. These look like an aerial shell but feel somewhat heavier because of their solid construction.



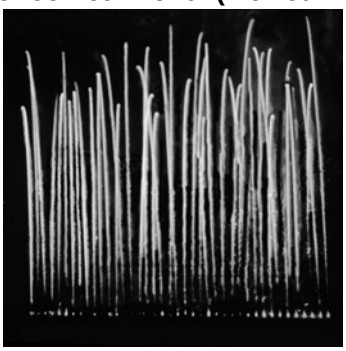
Firework Comet Effect

- Most small comets (< 2.5 inches) are supplied as a unit, already loaded into their firing mortar.



Firework Comet Front

- Appearance of comet "front" (viewed from a distance).



Firework Comet Characteristics

- Large caliber comet shells are loaded and fired from mortars using the same procedure as for aerial shells. However, their greater mass will put a greater stress on the mortar and mortar plug.
- Large comets may have burn times of six or more seconds. Because of the long burn time, if such a comet is weakly propelled, there is a chance that it will fall to the ground while still burning.

Firework Comet Characteristics

- The most common sizes for comet shells are 2 to 4 inch. However, both smaller and larger sizes are used. Smaller comets generally are not made for individual firing but are typically fired in groups described as "comet batteries".
- Comets will often be propelled to a greater height than an aerial shell of the same size, because of its relatively high mass, which does not cause it to slow down as quickly from aerodynamic drag forces.

Firework Comet Malfunctions

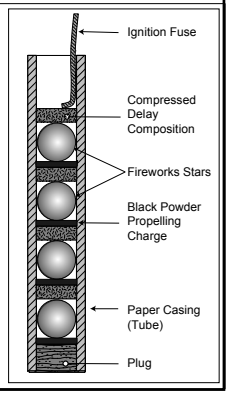
- **Comet shells suffer some of the same malfunctions as do aerial shells.**
  - **Burning Fallout – fragments not rising to full height – accidental ignitions**
  - **Hangfire or Misfire - abandon use of the mortar and clear after display**
  - **Shell "Detonations" – bury or barricade mortar**
  - **Mortar Failures – caused by greater pressures – comet may fall to the ground**

Firework Roman Candles

- **Roman candles propel a series of projectiles into the air typically with a few seconds delay between firings.**

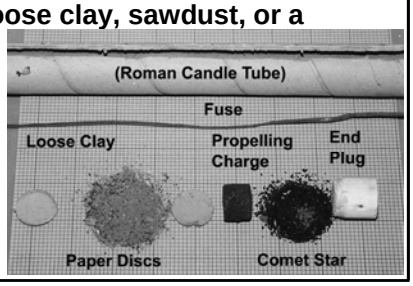
Firework Roman Candles

- **The delay between firings is sometimes provided by a slow burning composition ("candle comp.", a hand-made Black Powder with added charcoal).**
- **The propelling charge is loose granular Black Powder.**



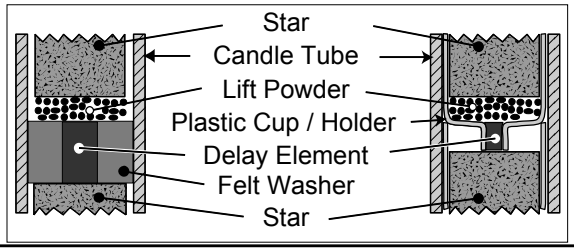
Roman Candles Delay Elements

- **Small and relatively inexpensive Roman candles may use one or two fuses running along the inside wall of the tube and inert filler (e.g., loose clay, sawdust, or a mixture) providing separation between shots.**



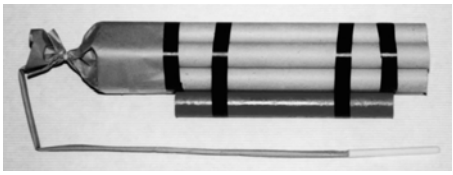
Roman Candles Delay Elements

- **Display candles have precise firing delays, commonly using pressed delay elements or short lengths of time fuse held in felt washers or in special plastic holders.**



Firework Roman Candle Battery

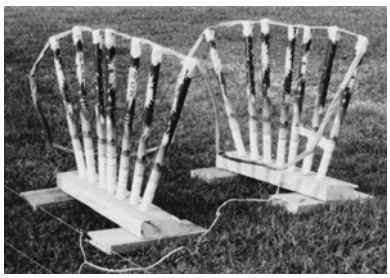
- **A group of Roman candles fused together to fire simultaneously, forming a candle battery.**



- **The projectiles will usually be firework stars (colored or tailed) or they can be small shells, whistles, reports, etc.**

Firework Roman Candle Battery

- A Roman candle battery made using consumer Roman candles to make a fanned-out display.



Roman Candle Characteristics

- A Roman candle is a chain-fused item. That is to say, a series of projectile firings occur after a single ignition.
  - As chain fused items, Roman candles require added separation distance.
  - Extra care should be taken in mounting and barricading Roman candles so they do not become misaligned and send burning material in dangerous directions.

Roman Candle Characteristics

- Common sizes of Roman candles range from 3/8-inch to 2-inch tube ID.
  - Roman candles up to 3 inches in diameter firing aerial shells have become available. (These must be separated from spectators at least as far as chain-fused aerial shells of the same size.)
  - Typically, Roman candles fire from 5 to 10 projectiles.
  - The projectiles range from about 50 feet to well over 250 feet in height.

Roman Candle Malfunctions

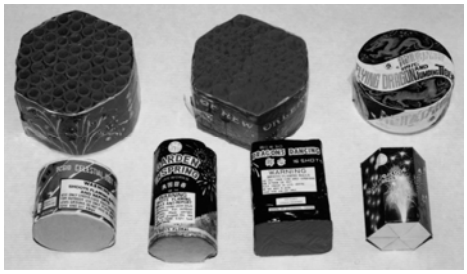
- Many Roman candle malfunctions do not pose a significant safety problem:
  - Incomplete firing, with some of the shots remaining unfired.
  - Multiple near simultaneous firings.
  - Delayed firings; longer than normal delay intervals.

Roman Candle Malfunctions

- Some Roman candle malfunctions can pose safety problems:
  - Projectiles may fall to the ground to ignite combustibles or other fireworks.
  - Tube blowout could cause a Roman candle battery to dislodge from its support, with some Roman candle projectiles then firing in dangerous directions.
  - Some Roman candle star formulations have produced powerful in-tube explosions similar to aerial shell “detonations”.

Cakes and Multi-Shots

- Cakes and multi-shots have a number of individual small chain-fused mortars, and they propel a series of effects into the air.



Cakes and Multi-Shots

- Display boxes containing approximately 1-inch diameter items (100 and 150 shots).

Cakes and Multi-Shots

- As chain fused items, cakes require added separation distance.

- Extra care should be taken in mounting and barricading cakes and multi-shots so they do not become misaligned and send burning material in dangerous directions.

Cake and Multi-Shot Characteristics

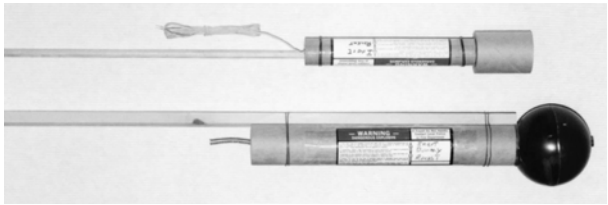
- The number of tubes typically ranges from about 7 to 100 but can have many more.
- The internal diameter of the individual tubes typically ranges from about 3/8 inch to 1 inch but can be as large as 3 or 4 inches in boxed finales.
- The projectiles can be firework stars (colored or tailed), small aerial shells, whistles, reports, etc.

Cake and Multi-Shot Characteristics

- The interval between firings can range from a small fraction of a second to several seconds.
- Malfunctions are much the same as those of Roman candles.

Fireworks Rockets

- A firework rocket combines a small aerial shell (rocket heading) with a rocket motor for propulsion. Generally, the rocket produces an upward trail of sparks and then a display from the rocket heading.

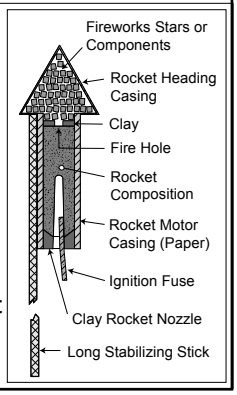


Fireworks Rockets

- Rockets use a long thin stick for stability.
- One apparatus used to help aim and guide rockets during the start of their flight (rocket sticks are inserted into the tubes).

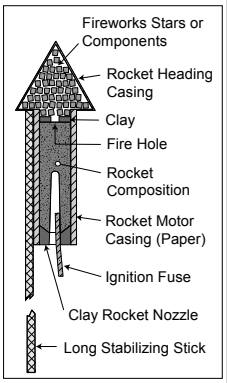
Fireworks Rockets

- **Rockets have three major disadvantages:**
  - **Only carry a lightweight heading, to produce only a small display.**
  - **Can travel great and unpredictable horizontal distances.**
  - **Fall to the earth somewhat like an arrow.**



Fireworks Rockets

- **Because of the major safety disadvantages, rockets are rarely if ever used in public displays.**



Fireworks Rocket Characteristics

- **Display firework rockets have rocket motors that range in size from about 3/4-inch and 7-inches long to about 1-1/4-inches ID and 15-inches long.**
- **These rockets can reach heights of 1000 feet or more and can carry nearly a pound as a heading to produce a display.**

Fireworks Rocket Malfunctions

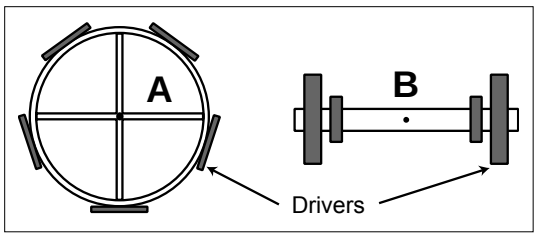
- **Nearly all rocket malfunctions pose a threat to safety.**
  - **If a rocket veers off course or is deflected off course, it may travel a great distance in a dangerous direction before functioning; thus posing a fire or explosion hazard far from its point of launch.**
  - **If a motor explodes shortly after ignition, the heading will generally explode at the same time or shortly thereafter. This may shower the ground with burning materials.**

Fireworks Rocket Malfunctions

- **Rocket malfunctions – Safety (Continued).**
  - **If a rocket heading is a dud (does not explode), the spent rocket and live heading may fall to the ground, possibly a very great distance from where it was fired.**
- **Even if a rocket functions properly, it may still pose a safety hazard.**
  - **The spent rocket casing and attached stick may fall to the ground (somewhat like an arrow) a very great distance from where it was fired.**

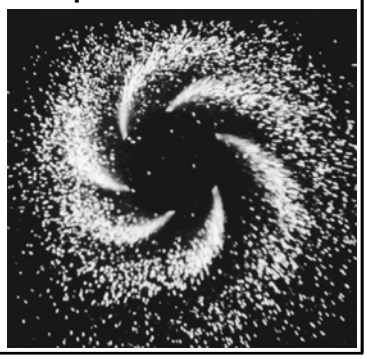
Fireworks Wheels

- **A typical firework wheel has a number of spark and thrust producing "drivers" attached to a framework freely rotating about a central hub or axle.**



Fireworks Wheels

- Firework wheel examples:

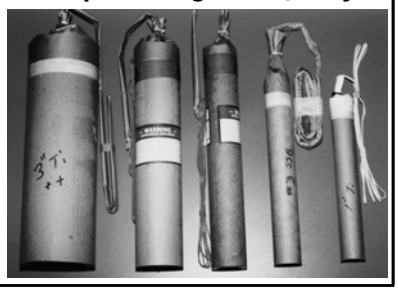


Wheel Characteristics and Malfunctions

- There are vertical and horizontal wheels, which are designed to rotate in the vertical or horizontal plane, respectively.
- The size and number of drivers range widely, as do the number and type of other pyrotechnic items attached to the wheel.
- Malfunctions: About the only malfunctions that threaten safety are if drivers or devices fly from the wheel, or if the wheel comes loose and rolls along the ground.

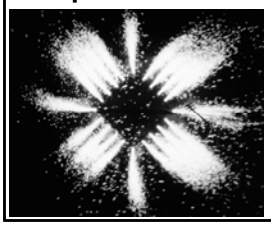
Fountains, Gerbs and Waterfalls

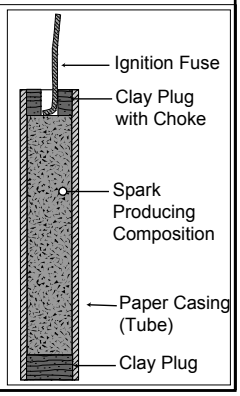
- Fountains and gerbs are the same. They are called fountains when used individually and placed upon the ground; they are called gerbs when attached to a frame or wheel.



Fountains, Gerbs and Waterfalls

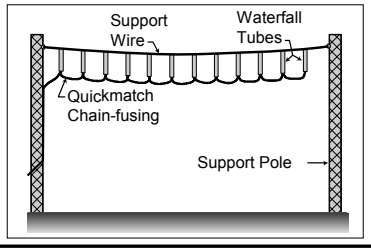
- A tube packed with a spark producing composition, partially closed with a plug to make its sparks extend farther.





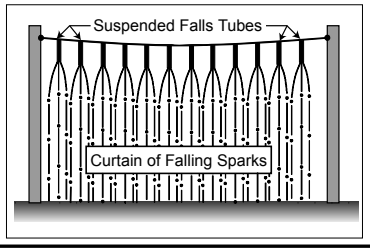
Fountains, Gerbs and Waterfalls

- Waterfalls are made by suspending gerb-like devices upside-down from a wire above the ground, usually chain fused using quick match.



Fountains, Gerbs and Waterfalls

- Waterfalls produce a wall of sparks falling downward. Unlike gerbs, waterfalls typically have open-ended tubes (without chokes).



Fountains, Gerbs and Waterfalls

- **Characteristics:**
  - **Fountains generally range from 1/2-inch ID and 5-inches long to at least 3-inches ID and more than 12-inches long. Gerbs and waterfall tubes rarely exceed 1-inch ID.**
  - **The projected sparks from fountains range in height from about 3 ft to more than 20 ft.**
  - **Burn time for these items ranges from less than 5 seconds to more than a minute.**
  - **Spark colors range from dim gold to bright white, depending on the composition used.**

Fountains, Gerbs and Waterfalls

- **Malfunctions:**
  - **If the internal pressure exceeds the strength of the tube, it will explode. This malfunction is not likely to cause a spectator injury (unless the explosion damages or repositions other fireworks).**
  - **If the item comes loose from its mounting, it might dangerously propel itself.**

Crackling Wheel – Crackling Whip

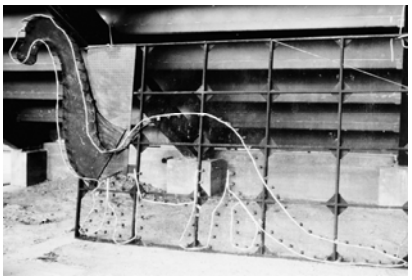
- **Occasionally a consumer firework called "crackling wheel" or "crackling whip" is used to produce a waterfall-like effect. The long cord-like items are unwound and a large number of them are hung from a long wire. Upon burning, a curtain of crackling sparks is produced.**

Lancework

- **Lancework is literally a "picture in fire". Typically lancework forms the outline of a familiar object or spells out words.**

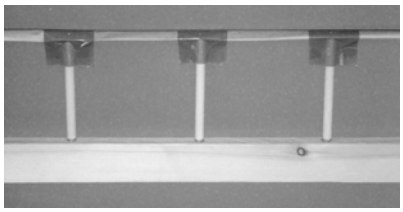
Lancework

- **Lancework is made by attaching many small tubes (lance tubes) containing colored flame producing composition to a framework to form the desired pattern.**



Lancework

- **Lance tubes are typically attached to the frame by pressing them onto exposed headless nails and gluing them in place. Most commonly, the lance tubes are all chain fused using quick match attached to their tips.**

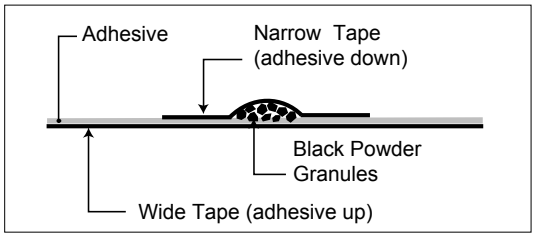


Lancework

- **Characteristics:**
  - **Lance tubes are typically about 3/8-inch in diameter by 4-inches long.**
  - **Lance composition can burn to produce various colors and may produce sparks.**
  - **Generally, lance burns from 40 to 60 sec.**
- **Malfunctions:**
  - **There is essentially no way for a lancework to injure spectators unless there are other pyrotechnic devices included in its design.**

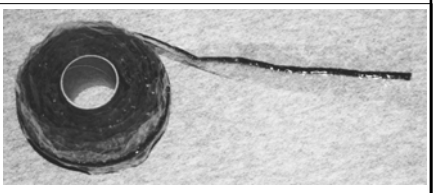
Lancework – Sticky Match Fusing

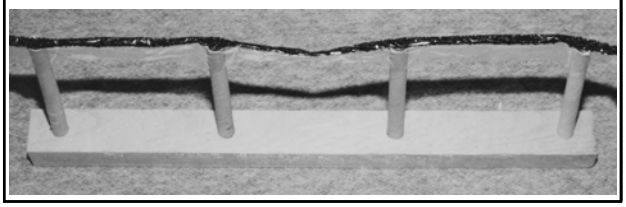
- **Sticky Match™ is a fuse material that makes fusing lancework easier. It is formed from two-widths of plastic tape with a trail of Black Powder between.**



Lancework – Sticky Match Fusing

- **Sticky match roll and on lance tubes.**





Lancework – Sticky Match Fusing

- **Unlike quick match, the burn rate of Sticky Match is temperature dependent and can be quite slow in very cold weather.**
- **Sticky Match is also somewhat more sensitive to accidental ignition from sparks than quick match.**

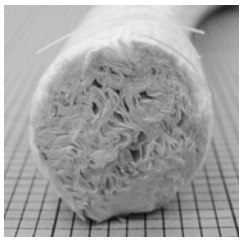
Temperature (°F)	Burn Rate (ft/s)
100	4.5
58	4.0
12	2.0
–18	1.0

Fire Rope

- **Although not strictly a pyrotechnic effect, Fire Rope and designs produced with it are somewhat commonly used in other countries and have been introduced into the US.**

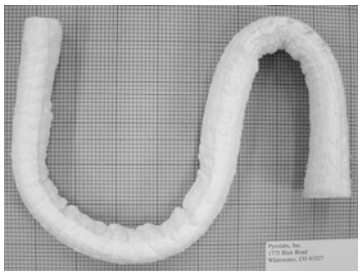
Fire Rope

- **Fire Rope is a thick cord of absorbent material (~1 inch in diameter) formed around a malleable central wire that helps to hold the Fire Rope in its intended shape.**



Fire Rope

- **To creat a Fire Rope display:**
  - **Bend Fire Rope segments into the intended design and secure to a non-combustible framework.**
  - **Soak with a flammable liquid.**
  - **Ignite; burns for 10 to 15 minutes.**



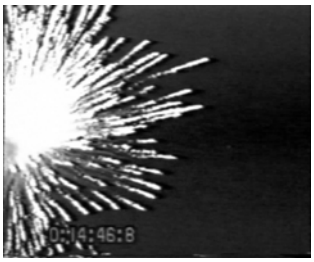
End of Unit

General Display Site Requirements

- Display site size
- Site security
- Other site requirements
- Site plan
- Fireworks display permitting
- Floating vessels and platforms requirements
- Rooftops and other limited egress locations requirements

Display Site Size

- Display site: A fireworks display surrounded by people and property needing protection.
- Display site size is the single most important factor regarding public safety. (Video)



Display Site Size

- The minimum radius of the site is 70 feet per inch of internal mortar diameter of the largest size shell in the display.
- Many countries require larger sites and the NFPA has considered increasing the separation distance but has not done so.
  - People are from 3 to 5 times more likely to be killed or seriously injured on the round trip drive to watch a fireworks display than they are to be killed or seriously injured by the fireworks from the display.

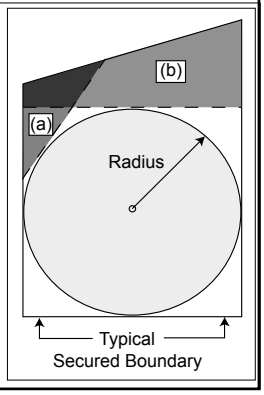
Display Site Size

- The required display site size is based on the largest shell size to be used in the display.
- [Video]

Largest Aerial Shell Size		Minimum Radius of Display Site	
in.	mm	ft.	m
<1	<25	75	23
1.5	38	105	32
2	50	140	43
2.5	63	175	54
3	75	210	64
4	100	280	85
5	125	350	107
6	150	420	128
7	175	490	149
8	200	560	171
10	250	700	213
12	300	840	256
>12	>300	Approval of the Authority Having Jurisdiction	

Display Site Size

- What determines the largest size shell that can be used is the radius of the circle drawn inside the site boundary.
- Added space in some portion of the site (e.g., "a" or "b") does not allow larger shells.



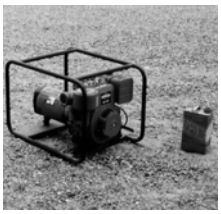
Display Site Size

- When an accident could be especially severe, the size of a display site generally must be doubled in the direction of the hazard. For example:
  - When near a hospital or prison (i.e., when there are people with limited mobility).

Display Site Size

- **When an accident could be especially severe, … doubled …. For example:**
  - **When near large amounts of certain hazardous materials (e.g., toxic, flammable, or explosive materials).**





Site Security

- **Site security must be initiated immediately upon the arrival of the fireworks.**
  - **This level of security can usually be provided by the display crew on site as opposed to needing to hire security guards.**
- **Security requirements:**
  - **No unescorted persons (non-crew members) are allowed in the area of the fireworks.**
  - **No smoking within 50 feet (15 m) of any fireworks.**

Site Security

- **Security requirements** (continued)**:**
  - **No person present that is using alcohol or drugs.**
  - **Protection of fireworks from theft.**
  - **The fireworks are never left unattended.**
  - **Protection of fireworks from weather damage (when necessary).**
  - **Protection of fireworks from sparks (e.g., kids shooting fireworks toward the discharge site).**

Site Security

- **Security requirements** (continued)**:**
  - **Only the operator, authorized assistants, and the authority having jurisdiction are permitted in the discharge area during the display.**
  - **Barriers and warning signs are appropriate to help control spectators.**

Site Security

- **Site security is made easier when:**
  - **Boundaries are easily secured.**
  - **The discharge site is on barges on a large body of water and patrol boats are present.**
  - **Ample crowd control monitors are present.**
  - **The local population respects authority and generally behaves responsibly.**
- **Security must remain in effect after the display until the area has been inspected and declared safe by the operator.**

Other Site Requirements

- **There must be no overhead obstructions within 25 ft of the firework mortars.**
  - **Obstructions include wires, tree limbs, light poles.**
  - **An obstruction could cause the redirection or explosion of an aerial shell striking the object.**

Other Site Requirements

- The display site must be:
  - Free of spectators, spectator vehicles, etc.
  - Mostly free of combustibles.
  - A "mostly open area".

Other Site Requirements

- An unacceptable "large open area".
  - Tall thick grass makes a fire likely, and it will be nearly impossible to locate duds.

Other Site Requirements

- Unoccupied buildings are allowed in the site, with the permission of the Authority Having Jurisdiction and the owner.
  - Occupants are allowed provided the structure affords sufficient protection.

Site Plan

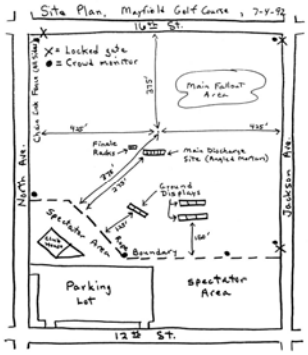
- Site Plan — Why make one?
  - It probably will be required for the permit application.
  - It will help to decide what supplies and equipment are necessary for the display.
  - It will help to evaluate the appropriateness of fireworks to be displayed.
  - It will help to decide on the appropriate number and placement of crowd monitors.
  - It will facilitate the rapid setup of the display.

Site Plan

- Site Plan — What should be included?
  - Critical distances must be shown, but the plan need not be drawn to scale.
  - The planned location of fireworks and equipment.
  - The secured boundaries, and the location and number of crowd control monitors.
  - The location of spectator and parking areas.
  - Note anything needing special attention.

Site Plan

- An example of a site plan.



Fireworks Display Permitting

- A display permit is required.
  - Apply early – at least 2-weeks before show.
  - Supply all permit application information:
    - Site Plan for the display site.
    - Fireworks list including aerial shell sizes.
    - Documentation of insurance.
    - Names and license information of the Company and the Operator, and the name of the Sponsor.
    - Where fireworks will be stored before the display.
    - Date and time of display (also any rain date).

Fireworks Display Permitting

- Authority Having Jurisdiction:
  - Must inspect the site well in advance of the display and give formal approval or rejection.
  - Should inspect the actual set-up on the show day.
- When the Authority Having Jurisdiction is also acting as the operator of the display, they must meet all normal requirements for conducting a display.

Possible Break Point

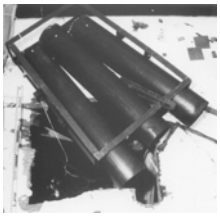
- End here if not discussing displays fired from barges and floating platforms at this time.
  - Return to menu.
  - Start next unit.
  - APA Barge Video.

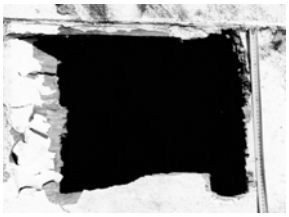
Floating Vessels – Requirements

- Displays from floating vessels and platforms may be manned or unmanned, but must be kept under control.
- All requirements for on-land sites apply to displays from floating vessels and platforms.

Floating Vessels – Requirements

- The decking must be sufficiently strong and stable for the safe firing of the show.
- An example where a wooden barge deck was not sufficiently strong.





Floating Vessels – Safety Shelter

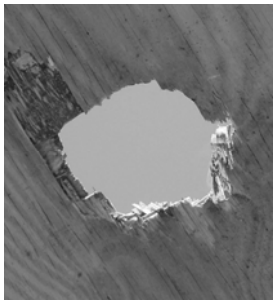
- Floating vessels manned during an electrically fired display must have a safety shelter. (Manually fired displays must have a protective barrier for all non-firing personnel.)
- Safety Shelter Construction, it must:
  - Be large enough to accommodate all personnel present.
  - Have at least 3 sides and a roof, each made of at least 3/4-inch (18-mm) plywood or equivalent material.

Floating Vessels – Safety Shelter

- **Placement requirements for safety shelter:**
  - **The safety shelter must be separated from mortars by 2 feet per inch of the mortar diameter for mortars up to 6 inch and 4 feet per inch of the mortar diameter for mortars greater than 6 inch.**
  - **However, it should not be expected that the safety shelter will be sufficient to protect the crew from the direct impact of even a small caliber aerial shell.**

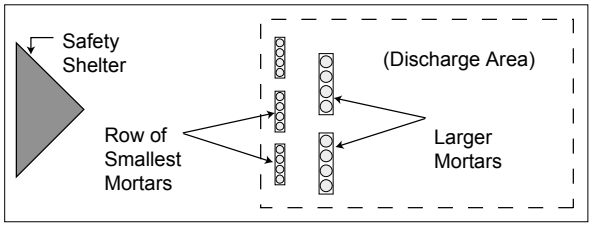
Floating Vessels – Safety Shelter

- **Test of a 3-inch shell impacting a ¾-inch plywood panel. (Video)**



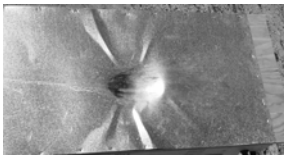
Floating Vessels – Safety Shelter

- **Improved safety shelter design, based on limited testing:**
- **45° angling of the front wall of the shelter resists penetration of some 4-inch shells.**



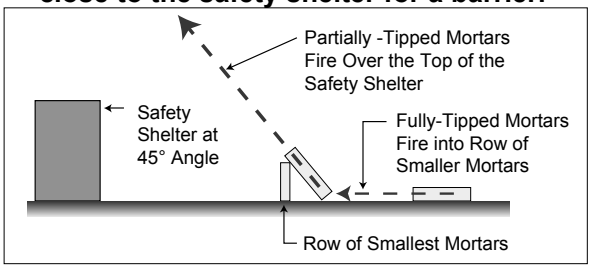
Floating Vessels – Safety Shelter

- **Improved safety shelter design, based on limited testing** (continued)**:**
  - **A layer of 0.024 inch sheet metal on the surface of the ¾-inch plywood resists penetration of most 5-inch shells.**
  - **A 45° angling plus sheet metal resists penetration of most 6-inch shells. (Video)**



Floating Vessels – Safety Shelter

- **Improved safety shelter design** (continued)**:**
- **Using a row of small diameter mortars close to the safety shelter for a barrier.**



Floating Vessels – Requirements

- **Personal floatation devices are required to be worn by all personnel.**
- **There must be at least two unobstructed egress paths from every point on the floating vessel.**
  - **However, only one safe egress path is required from the safety shelter.**
  - **The egress path from the safety shelter should not require fleeing persons to pass through or approach the area(s) in which the fireworks are located.**

Floating Vessels – Requirements

- All non-essential combustible and flammable materials must be removed from the floating vessel.
  - Tank vessels and platforms must be certified as being free of combustible and flammable gas.
  - Exception: fuel supplies for generators and for vessel movement are allowed.
  - If the floating vessel or platform has a wooden deck, consideration should be given to covering it with sand to retard fire.

Floating Vessels – Size

- The minimum size for floating vessels and platforms includes the minimum area of the display setup PLUS the area needed for the safety shelter.
- The minimum required size of the floating vessel or platform depends on the type and amount of fireworks to be discharged from it.

Floating Vessels – Size

- The size for electrically-fired displays:

  Barge Area (ft^2) = M + C + G

  where M = the area required for mortars,
  C = the area required for cakes and multi-shot devices, and
  G = the area required for ground devices.
- The size for manually-fired displays is twice that for electrically-fired displays.

Floating Vessels – Size

- The area required for mortars and racks (M) is calculated using:

  $M\ (ft^2) = ½\ \Sigma\ M_n\ D_n$

  where M_n = the number of each size mortar from 1 to n, and
  D_n = the inside diameter (in inches) for each size mortar.

Floating Vessels – Size

- For example, if a setup is to include:

  100 3-inch mortars
  50 4-inch mortars
  20 5-inch mortars

  Then:

  $M\ (ft^2) = ½\ \Sigma\ M_n\ D_n$
  $M = ½\ [(100 \times 3) + (50 \times 4) + (20 \times 5)]\ ft^2$
  $M = ½\ [(300) + (200) + (100)]\ ft^2$
  $M = ½\ (600)\ ft^2 = 300\ ft^2$

Floating Vessels – Size

- The area required for cakes and multi-shot devices (C) is calculated using:

  $C\ (ft^2) = 2\ \Sigma\ C_n\ F_n$

  Where C_n = the number of each size cake or multi-shot device from 1 to n,
  F_n = the footprint (in ft^2) for each size device.

Floating Vessels – Size

- For example, if a setup is to include:
  - 16 Cakes with footprint of 0.8 ft^2
  - 8 Multi-shots with footprint of 1.5 ft^2

Then:

$C\ (ft^2) = 2\ \Sigma\ C_n\ F_n$

$C = 2\ [(16 \times 0.8) + (8 \times 1.5)]\ ft^2$

$C = 2\ [(12.8) + (12.0)]\ ft^2$

$C = 2\ (24.8)\ ft^2 = 49.6\ ft^2 = 50\ ft^2$

Floating Vessels – Size

- The area required for ground displays (G) is calculated using:

$$G\ (ft^2) = \Sigma\ G_n\ A_n$$

where G_n = the number of each different ground display item from 1 to n,

A_n = the area occupied by each different ground item.

Floating Vessels – Size

- For example, if a setup is to include:
  - 8 fountain bouquets each occupying 3 ft^2
  - 1 lance work occupying 20 ft^2

Then:

$G\ (ft^2) = \Sigma\ G_n\ A_n$

$G = [(8 \times 3) + (1 \times 20)]\ ft^2$

$G = [(24) + (20)]\ ft^2$

$G = 44\ ft^2$

Floating Vessels – Size

- Based on the preceding examples, the overall minimum area of the floating vessel for this electrically fired display is:

Minimum Area = M + C + G

Minimum Area = $(300 + 50 + 44)\ ft^2$

Minimum Area = $396\ ft^2$

- Note: This does not include the area needed for the safety shelter.

Floating Vessels – Size

- Had this been a manually fired display, it would have required twice the barge area.

Minimum Area (manual) = $2\ (396)\ ft^2$

Minimum Area (manual) = $792\ ft^2$

- When more than the minimum area is available, items should be spread out to the extent that provides for greater safety.

Roof Top and Limited Access Sites

- Displays may be fired from roof tops and limited egress locations providing that:
  - The location is sufficiently strong and stable to allow the safe firing of the display.
  - The Authority Having Jurisdiction and structure owner (or authorized agent) have given their approval.
  - The operator has the needed level of knowledge and experience to safely set-up and perform the display.

Roof Top and Limited Access Sites

- Except as noted, all of requirements for normal display sites plus those for floating vessels must be met. In addition:
  - All openings must be covered to prevent any damage or the entry of burning material.
  - All air intake openings must be covered to prevent smoke from entering.
    - As an alternative, the ventilation or other systems may be shut down during the display.
  - The AHJ and structure owner (agent) must determine whether measures are needed to protect the surface of the structure.

Roof Top and Limited Access Sites

- If personnel will be present during the display, a safety area must be provided.
  - The safety area must be at least 75 feet from the nearest mortar or 15 feet if sufficient additional protection is provided.
    - Examples of added protection are barricades or sandbags on the side of the mortars.
  - If a floating vessel safety shelter is used, then a safety area is not required.
  - The emergency paths must be unobstructed and not pass through the discharge site.

Roof Top and Limited Access Sites

- Tall structures will generally require added spectator separation distances because errant fireworks may travel greater distances before reaching the ground.
  - The appropriate amount of added spectator separation distance has not been quantified at this time.

End of Unit

Fireworks Display Equipment

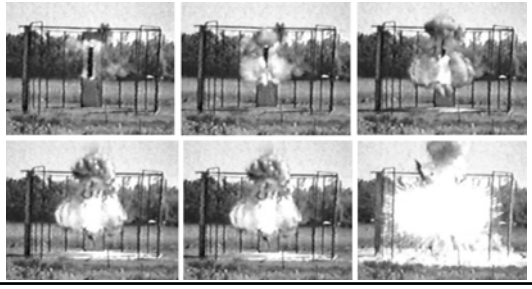
- Firework mortar types
- Firework mortar requirements
- Mortar inspections
- Mortar racks, boxes (troughs) and barrels
- Ready box
- Other display equipment
- Personal safety equipment
- Emergency equipment

Firework Mortars

- All mortars are capable of producing dangerous flying debris when aerial shells explode within them.
- When personnel are near firing mortars, some type of barricading should be provided.

Firework Mortars

- The Canadian Explosives Research Lab (CERL) conducted tests of mortars with shells exploding within them.

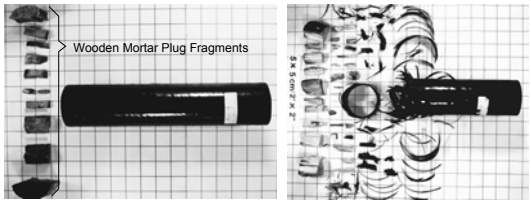


Firework Mortars

- It is not possible to rank the relative safety of mortars under all conditions in a single list. However, the following is an attempt to do that for typical conditions of a manually fired display.
  - In the photos to follow, the results of a star shell explosion is on the left and the results of a salute explosion is on the right.

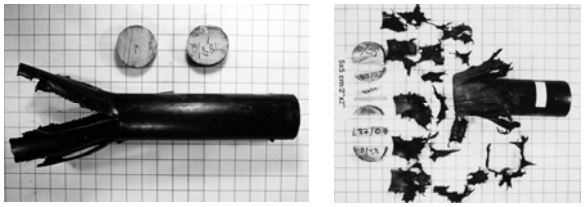
Firework Mortars

- Approximate safety ranking of mortars:
  1) FRE — Fiber Reinforced Epoxy (Fiberglass) —Mortar fragments are generally of relatively low hazard. A wooden plug can become a dangerous fragment(s).



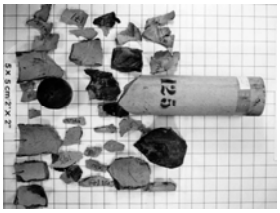
Firework Mortars

- Approximate safety ranking of mortars:
  2) HDPE — High Density Polyethylene — Mortar fragments are generally of moderately low hazard. A wooden plug can become a dangerous fragment(s).



Firework Mortars

- **Approximate safety ranking of mortars:**
  - **3) Paper/Cardboard — Either spiral- or convolute-wound tubes. Mortar fragments are of moderately low hazard. The wooden plug can produce a dangerous fragment(s).**

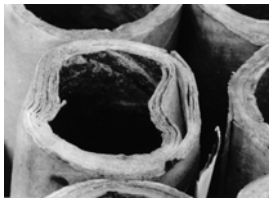


Firework Mortars

- **Approximate safety ranking of mortars:**
  - **3) Paper/Cardboard** (Continued)**:**
    - **Generally paper mortars that are placed in the ground or sand will need to be protected from moisture using a plastic bag or equivalent.**

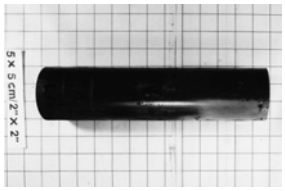
Firework Mortars

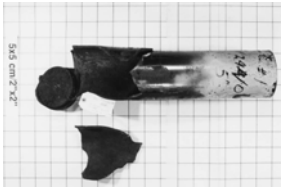
- **Approximate safety ranking of mortars:**
  - **3) Paper/Cardboard** (Continued)**:**
    - **Loose internal wraps of paper can cause an aerial shell to get caught when fired from the mortar and can cause malfunctions as a result. Also the mortar itself may catch fire.**



Firework Mortars

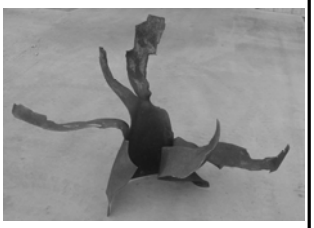
- **Approximate safety ranking of mortars:**
  - **4) Thick Steel — Schedule 40 steel pipe. The strength is usually sufficient for an exploding star shell, but when they do rupture, from a salute or star shell "detonation" they produce very dangerous fragments.**





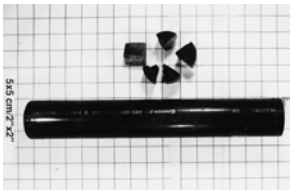
Firework Mortars

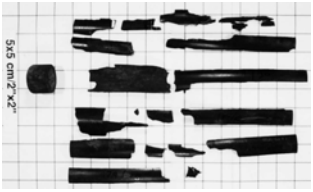
- **Approximate safety ranking of mortars:**
  - **4) Thick Steel** (continued)**: A 5- and a 12-inch steel mortar, destroyed by shell detonations.**



Minimally Acceptable Mortars

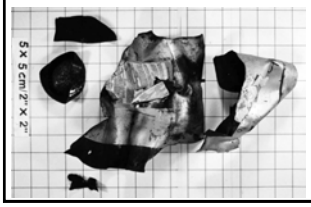
- **Approximate safety ranking of mortars:**
  - **5) ABS — Acrylonitrile-Butadiene-Styrene) A somewhat resilient plastic of moderate strength. Fragments are substantially more hazardous than those from HDPE mortars.**

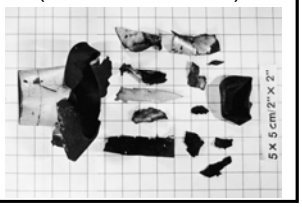




Minimally Acceptable Mortars

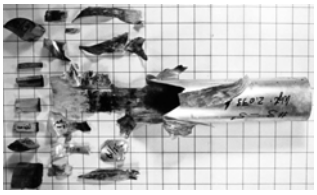
- **Approximate safety ranking of mortars:**
  - **6) Sheet Steel and Aluminum — These mortars are much weaker than Schedule 40 steel and fail more often. At close range fragments are quite dangerous, but their range is less than for thick steel mortars.** (sheet steel-below)





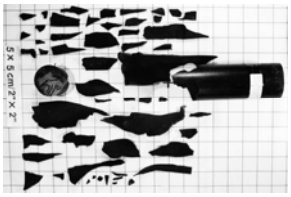
Minimally Acceptable Mortars

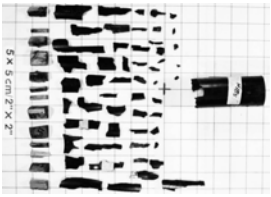
- **Approximate safety ranking of mortars:**
  - **6) Sheet Steel and Aluminum** (Continued)**:** (Aluminum – below)



Unacceptable Firework Mortars

- **Approximate safety ranking of mortars:**
  - **Unacceptable mortar types:**
    - **PVC — (Polyvinyl Chloride) — A moderate strength material, but it will often shatter from an internal explosion. At close range the fragments are very dangerous.**





Unacceptable Firework Mortars

- **Approximate safety ranking of mortars:**
  - **Unacceptable mortar types** (Continued)**:**
    - **Cast iron and ceramic tile pipe are unacceptable for mortars. The material is low strength and/or shatters to produce highly dangerous, long range fragments.**
    - **Other unacceptable mortar materials include stove pipe, corrugated culvert, clay, bamboo and wood.**

CERL Test Firework Mortars

- **Following are specifications for mortars displayed in the previous photos.**

Mortar	Size		Wall Thickness		Plug Length	
	in.	mm	in.	mm	in.	mm
FRE	5	125	0.09	2.4	3.1	79
HDPE + Plug	5	125	0.27	6.9	3.7	95
Steel - Sch. 40	5	125	0.26	6.6	0.5	13
ABS	4	105	0.20	5.2	2.6	65
Sheet Steel	5	125	0.03	0.8	0.6	15
Aluminum	5	125	0.08	2.1	2.9	73

- **All of the mortars used were new or virtually new prior to testing.**

Temperature Effects On Mortars

- **As the temperature is lowered, all materials become more brittle. This is particularly noticeable for plastic mortars.**

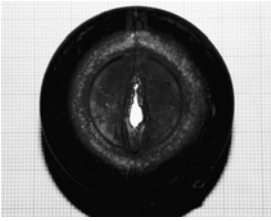
Material	Moderate Temp. ~ 70 ºF (~ 20 ºC)	Low Temp. < 0 ºF (<–17 ºC)
FRE	Low Hazard	Low Hazard
HDPE	Thin Pieces	Large Chunks *
ABS	Large Chunks *	Shatters +
PVC	Shatters +	Shatters +

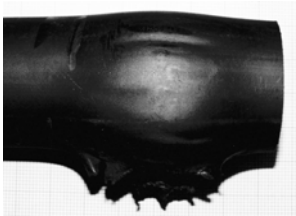
* **A safety concern if personnel are in the immediate area.**

\+ **The pointed and sharp nature of these fragments make the mortars unacceptable.**

Temperature Effects On Mortars

- If plastic mortars are fired repeatedly in a relatively short time span, the temperature of the mortar may rise to a point where it loses most of its strength and can fail.





Firework Mortar Requirements

- Mortar Diameter:
  - A reasonably close fit of the shell is necessary to contain the lift gas. However, it must be loose enough for the shell to slide freely.

Firework Mortar Requirements

- Mortar Diameter:
  - The mortar's internal diameter should be within ±1/16 in. of the nominal size.
  - The total clearance between shell and mortar wall is typically:

Aerial Shell Size		Typical Clearance (Total)	
(inches)	(mm)	(inch)	(mm)
2.5 to 4	63 to 100	1/4	6
5 to 6	125 to 150	3/8	9
8 to 12	200 to 300	1/2	12

Firework Mortar Requirements

- Mortar Strength:
  - The mortar must have sufficient strength to safely withstand normal shell firings.
  - For guidance for FRE, HDPE, steel, and paper mortars, see tables in NFPA-1123.
  - If there is doubt about the strength of a mortar, conduct a test.
    - For example, load a heavy aerial shell into the mortar after adding 50% extra lift powder. If the mortar survives, it has ample strength and a sufficient safety margin.

Firework Mortar Requirements

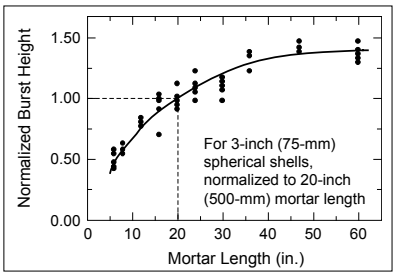
- Mortar Strength – (NFPA Table Example):
  - Fiber Reinforced Epoxy (FRE) Mortars.

Mortar ID (in.)	Adequate Mortar Wall Thickness (in.)[a]		
	Spherical[b]	Cylindrical Single-Break	Cylindrical Two-Break
2	0.07	0.11	0.11
2.5	0.07	0.11	0.11
3	0.07	0.11	0.11
4	0.11	0.11	0.11
5	0.11	0.11	0.11
6	0.11	0.11	0.11
8	0.25	(c)	(c)
10	0.25	(c)	(c)
12	0.25	(c)	(c)
>12	(c)	(c)	(c)

(Table Notes not included)

Firework Mortar Requirements

- Mortar Length:
  - Mortar length effects the height to which an aerial shell will be propelled.



Firework Mortar Requirements

- **Mortar Length:**
  - **A generally appropriate recommendation:**
    - **Shells <8" ID mortar length ≥5 times ID.**
    - **Shells ≥8" ID, mortar length ≥4 times ID.**
  - **Specific Guidance is provided by the NFPA.** (See next slide.)
  - **If in doubt about mortar length, conduct a test by firing a hard-breaking spherical shell. If its height is at least twice the star spread radius, the mortar length is sufficient.**

Firework Mortar Requirements

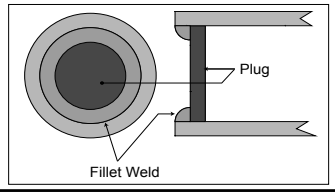
- **Mortar Length (NFPA Table):**
  - **Suggested Minimum Inside Mortar Length.**

Mortar ID (in.)	Minimum Mortar Length (in.)[a]		
	Single-Break	Double-Break	Up to 4-Break
2[b]	10	12	15
2.5[b]	12	15	18
3	15	18	21
4	20	23	27
5	24	28	32
6	28	32	37
8	34	40	46
10	40	46	54
12	46	52	62
>12[b]	(c)	(c)	(c)

(Table Notes not included)

Firework Mortar Requirements

- **Mortar Plugs:**
  - **Welded Plugs: In mortars, such as steel, aluminum and some plastics, a welded plug can be attached. This should be a "fillet" weld (not a "butt" weld). The plug should be at least as thick as the mortar wall.**



Firework Mortar Requirements

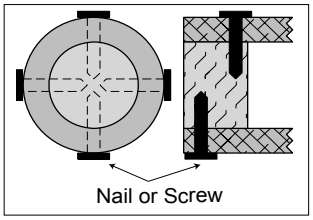
- **Mortar Plugs** (Continued)**:**
  - **Integral Plugs: For some types of plastic mortars, such as FRE and HDPE, the plugs may be molded or formed as an integral part of the mortar.**
    - **Generally, this is preferred because wooden plugs can become dangerous flying debris in the event there is an explosion within the mortar.**
    - **Also any screws or nails used to fasten wooden plugs can be weakened over time by corrosion and in a catastrophic failure, they can become an additional projectile hazard.**

Firework Mortar Requirements

- **Mortar Plugs** (Continued)**:**
  - **Wooden Plugs: Any mortar may be plugged using a wooden plug.**
    - **The plug must fit the ID of the mortar such that there are no gaps around the plug.**
    - **If the mortar is paper or cardboard, the plug should be equal in length and diameter.**
    - **For plastic and metal mortars, the plug thickness should be at least half the plug's diameter.**
    - **These plugs are generally nailed, screwed or bolted in place.**

Firework Mortar Requirements

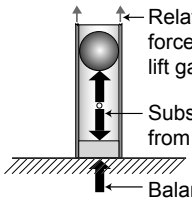
- **Mortar Plugs** (Continued)**:**
  - **Wooden Plugs** (Continued)**:**



  - **Concrete Plugs: Are not acceptable, they can be massive projectiles and will damage paper mortars when wet cement is added.**

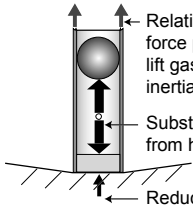
Below Mortar Support

- **When a mortar is strongly supported from below, only a relatively mild stress is placed on the plug fasteners.**



Below Mortar Support

- **When a mortar is weakly supported from below, a great stress is placed on the plug fasteners, and the plug may be blown out.**



Below Mortar Support

- **To reduce the chance of plugs blowing out, use a sufficient number of strong fasteners, and provide solid support below the mortars.**
- **Support is more of a problem with angled mortars, because one side (edge) of the mortar may be completely unsupported**

Mortar Inspections

- **An inspection of mortars is required before use and should include:**
  - **Mortars must be the proper diameter (test by inserting the aerial shells to be fired).**
  - **Mortar plugs must be secured with little or no gap between the plug and mortar wall.**
  - **There must be no constricting dents in the wall of the mortar.**
  - **Mortar must have reasonably clean interiors and be free of snags that could catch on an exiting aerial shell.**

Mortar Inspections

- **Inspection of mortars** (Continued)**:**
  - **Mortars should have reasonably smooth interiors. (Torn paper from the mortar can be a substantial concern for paper mortars.)**
  - **There should be no moisture deterioration. (This is especially a concern for paper mortars.)**
- **Defective mortars must not be used.**
- **It may be an aid to have the mortar size (ID) clearly marked on their top exterior.**

Mortar Racks

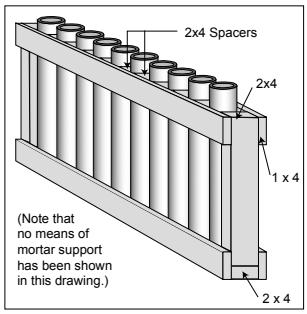
- **Sturdy rack construction is required. The rack should be able to withstand the explosion of a mortar within the rack.**
  - **Chain fusing (when a single ignition results in the firing of more than one aerial shell) requires especially strong mortar rack construction.**

Mortar Racks

- **Why you need strong racks:**

Mortar Racks

- **Sturdy rack construction** (Continued)**:**
  - **Typical wooden racks are not sufficiently strong. They can only be used for chain-fused shells when using twice the normal spectator separation distance.**

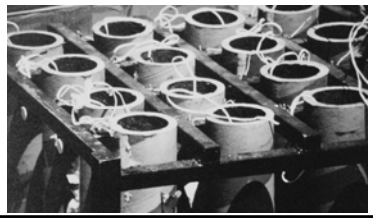


Mortar Racks

- **Wooden Mortar Rack Examples:**

Mortar Racks

- **Steel (i.e., strong) mortar racks:**



Mortar Racks

- **Safety is enhanced if the number of mortars per rack is low (mortar explosion).**
  - **Recommended and the required NFPA limits on the number of mortars:**

Size		Recommended Limit	NFPA Limits
in.	mm		
≤3	≤75	10	15
4	100	6	12
5	125	5	10
6	150	5	10
>6	>150	Not allowed	Not allowed

Mortar Racks

- **Limits on number of mortars** (Continued)**:**
  - **These limits should not apply to steel "matrix" or "dense-pack" mortar racks.**
  - **These limits do not apply to boxed finale items containing 2.5 inch or less diameter shells.**
- **Because the mortars are in direct contact with each other, bundles of mortars (without a rack) should not be used for aerial shells larger than 2 inch.**

Mortar Racks

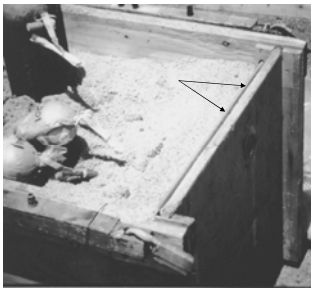
- Racks may only be used for mortars ≤6 inch.
  - 8-inch mortars can be used if mortars are non-metallic, not chain fused, and fired remotely.
- It is greatly preferred that heavy gauge steel mortars not be fired from typical racks.
- Fragments from both the mortars and the rack often become dangerous flying debris if a mortar in the rack explodes.
  - When manually firing from racks, barriers or sand bags are recommended for crew protection.

Sand Filled Boxes (Troughs)

- Properly constructed sand-filled wooden boxes or troughs are acceptable for the support of mortars.
  - Shells are setting on top of the mortars, ready for loading.

Sand Filled Boxes (Troughs)

- Two metal rods are required to be used for strength in holding the sides of the box together. Pairs of rods must be used at least every 4 ft of trough length.



Sand-Filled Barrels

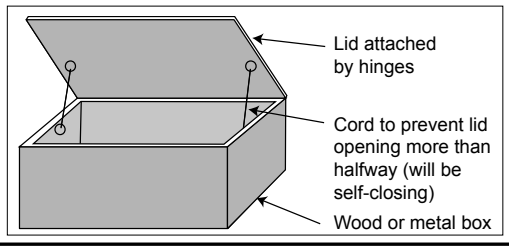
- Using sand-filled barrels is acceptable for the support of small numbers of mortars.

Sand-Filled Barrels

- Plastic garbage cans do not provide either sufficient strength or stability to be used in place of barrels.

Ready Boxes

- Ready boxes are used for shell storage during manually fired displays. They:
  - Should be of sturdy construction.
  - Must have an attached self-closing lid.



Ready Boxes

- Ready box examples:

Ready Boxes

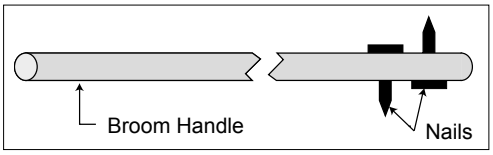
- To help protect the shells from sparks, the lid must be oriented to open on the side away from the mortars.
- A tarp covering the ready box is useful, but a tarp alone covering shells affords insufficient protection.

Ready Boxes

- Garbage cans are a poor choice.
  - Unattached lids that are not self closing.
  - They are too tall; sometimes requiring putting one's head well down inside them.

Other Display Equipment

- A mortar clean-out tool.
  - This can be a stick with nails that is used to clean debris from mortars.

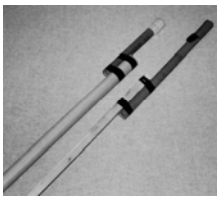


Other Display Equipment

- A mortar clean-out tool.
  - Use the clean-out tool only when necessary.
    - Cleaning mortars can be a very dangerous.
    - Mortars will usually clear themselves sufficiently well without cleaning.
    - A minor amount of debris left in a mortar has very little effect on aerial shell burst height.
    - Premature ignition from burning debris in the mortar could occur, but it is rare, and if it occurs, it should not result in an injury.

Other Display Equipment

- A fusee is often used to ignite fireworks.
  - The fusee should be attached to a stick or other extender.
    - An added 18 inches of separation should reduce the risk of serious injury from a mortar or shell explosion by about half.

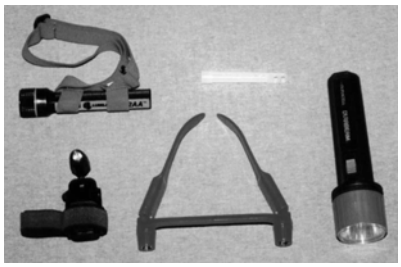


Other Display Equipment

- **A fusee to ignite fireworks.** (continued)
  - **There are potential problems with using a fusee for ignition of fireworks.**
    - **They produce dross that can accidentally ignite other fireworks.**
    - **They are quite bright. Making it hard to see dimly burning shell leaders.**

Other Display Equipment

- **Operational light:**
  - **If loaders and ready box tenders need light, that light must be from a non-flame source.**



Other Display Equipment

- **Security barriers:**
  - **A physical barrier is best (e.g., a fence).**
  - **At least a physical demarcation is needed.**
    - **For example, rope or fireworks barrier tape.**

Other Display Equipment

- **Communication equipment:**
  - **Monitor-to-operator communication is critical if crowd control is lost.**
    - **A flashlight signal is reliable if prearranged.**
    - **Radios are good, but batteries can fail.**

Personal Safety Equipment

- **Clothing (Minimum requirements):**
  - **Long-sleeved shirt and pants.**
  - **Clothing should be of heavy <u>COTTON</u> fabric.**
  - **Foot protection (at least closed-toe shoes).**

Personal Safety Equipment

- **Protective items for a manual display:**
  - **For all: head protection (hard hat or helmet), eye and hearing protection.**
  - **Face shield (at least for the shooter) and gloves are also recommended.**

Emergency Equipment

- **Fire fighting equipment:**
  - **A fire truck is best, but water fire extinguishers, garden sprayers, rakes and shovels provide a minimal fire-fighting capability.**

Emergency Equipment

- **First Aid Equipment:**
  - **During a display, EMTs on site are preferred.**
  - **First aid kit is good for minor crew injuries.**
  - **Ice is good for minor burn injuries. (Ice will often be available in beverage coolers.)**

End of Unit

Setups, Mostly for Manual Displays

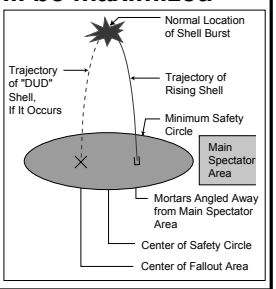
- Mortar placements
- Separation distance requirements
- Organization of mortars
- Burial of mortars
- Mortar angling for trajectory displacement and wind drift
- Placement of mortar racks and troughs
- Rack bracing, barricading and orientation
- Placement of ready boxes

Mortar Placement for Manually Fired Displays with Reloading

- For displays with reloading, if possible, the mortars should be angled from vertical and away from spectators.
  - Thus duds, low breaks and burning fallout from flowerpots will tend to be diverted away from the crew and the fireworks ready boxes.
  - This reduces the chance that these malfunctions will injure the crew or ignite shells in storage or while being loaded.

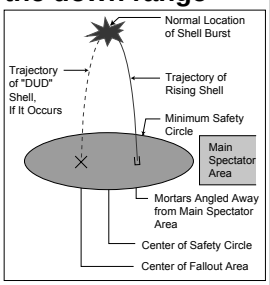
Placement of Angled Mortars

- When spectators are concentrated in one location, their safety will be maximized when the mortars are moved a little closer to the main spectator area, and the mortars are angled slightly away from the main spectator area.



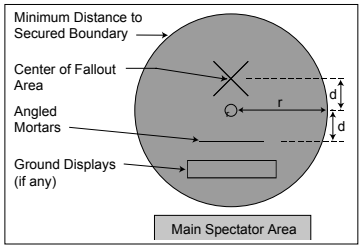
Placement of Angled Mortars

- Unless there is an excess of open (unoccupied) space in the down range direction, angled mortars must be offset from the center of the display site.



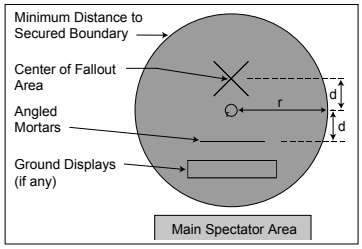
Placement of Angled Mortars

- The displacement (d) of the mortars from center of the display site toward the main spectator area may be up to 1/3 of the minimum required site radius (r).



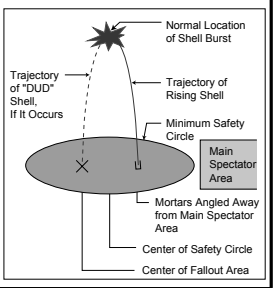
Placement of Angled Mortars

- The angle of the mortars must be such that on average a dud shell will fall at a point displaced the same distance (d) beyond the center of the display site.



Placement of Angled Mortars

- The offset increases public and crew safety because aerial shells and dangerous debris are moving away from spectators, the crew and stored fireworks.



Placement of Mortars

- When spectators surround a display site, angling of the mortars may pose a safety risk for those spectators that are down range from the mortars. In that case, it will generally be appropriate to position the mortars vertically.
  - With vertical mortars, the crew should take extra precautions for their personal safety.

Mortar Placement for Preloaded Manually Fired Displays

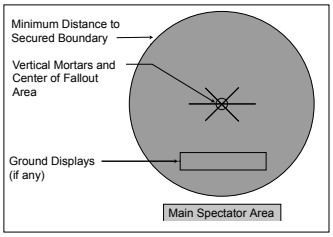
- There are substantially reduced risks to the crew from aerial shell malfunctions for preloaded manually fired displays with no reloading. This is because:
  - Fewer crew members will be present and at risk during the display.
  - No shells will be stored in the discharge area, and no one will be handling them.

Mortar Placement for Preloaded Manually Fired Displays

- Accordingly, if the crew desires, it is acceptable to fire the aerial shells from mortars that are placed vertically at the approximate center of the display site.
  - The crew will be at a somewhat greater risk but may choose to accept this risk.
- Unless the display site is large, vertical mortar placement is almost always preferred when spectators will completely surround the display site.

Placement of Vertical Mortars

- Vertically placed mortars, must be at the approximate center of the display site.
  - Note: If the display site is quite large, the mortars may be closer to spectators providing the separation distance requirement is met. (To be discussed.)



Mortar Placement for Electrically Fired Displays

- There are greatly reduced risks to the crew from shell malfunctions for displays that are electrically fired. This is because:
  - No crew members will be present and at risk in the discharge area during the display.
  - No shells will be stored in the discharge area, and no one will be handling them.

Mortar Placement for Electrically Fired Displays

- The mortars should either be placed vertically or angled, depending on which one maximizes spectator safety.
  - Vertical mortar placement is almost always preferred when spectators will completely surround the display site.
  - Angled mortars are almost always preferred when there are relatively few spectators in the down range direction (e.g., when firing over a large body of water.)

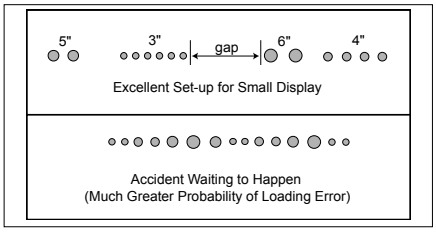
Separation Distance Requirements

- These are the minimum distances allowed.

Aerial Shell Size		Vertical Mortars		Angled Mortars[a,b]	
in.	mm	ft	m	ft	m
≤1	≤25	75	23	75	23
1.5	38	105	32	75	23
2	50	140	43	95	29
2.5	63	175	54	115	35
3	75	210	64	140	43
4	100	280	85	190	58
5	125	350	107	230	70
6	150	420	128	280	85
7	175	490	149	320	98
8	200	560	171	370	113
10	250	700	213	460	140
12	300	840	256	560	171

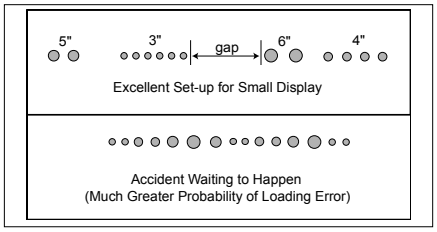
Organization of Mortars

- When mortars will be reloaded, proper organization of the mortars will substantially reduce loading errors (low breaks).
  - Mortars must be grouped together by size.



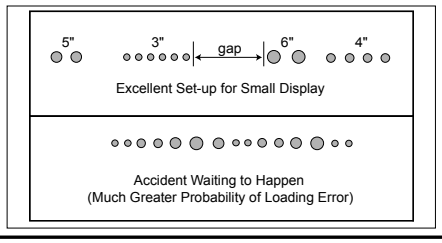
Organization of Mortars

- … proper organization of the mortars …:
  - A gap between each size grouping.
  - Groupings differ by more than one shell size.



Organization of Mortars

- For preloaded displays (loading is done during daylight without rushing) loading errors are rare. Accordingly, there is no requirement to organize mortars by size.



Burial of Firework Mortars

- For manually fired displays, mortars are often emplaced by partially burying them in the ground.
  - This requires little or no special equipment.
  - This affords an acceptable level of crew protection and a relatively high level of spectator protection in the event of an explosion of a mortar.
  - The ground provides the support needed to hold the mortars in their proper alignment.

Burial of Firework Mortars

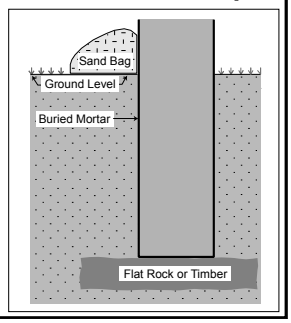
- **The depth of burial must be at least 2/3 the mortar length, measured from the original ground surface. However, burial to a depth of at least 3/4 their length is recommended as this gives significantly greater protection in the event of a mortar explosion.**

Burial of Firework Mortars

- **For additional crew protection on manually fired displays, sand bags or other barriers should be placed up to the approximate level of the muzzle of metal mortars. (Also recommended for non-metal mortars.)**

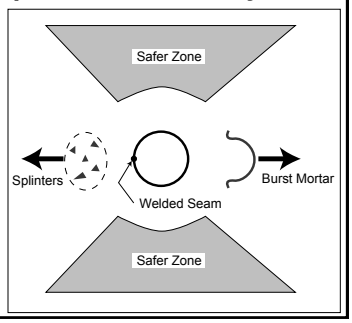
Burial of Firework Mortars

- **When the ground is soft, it is necessary to place support below the mortars to keep them from sinking as they are fired.**
  - **For example, use timbers or flat rocks for support.**



Burial of Firework Mortars

- **When seamed metal mortars are used, the seams should be placed so that they face right or left as viewed from the main spectator area.**



Burial of Firework Mortars

- **Moisture protection:**
  - **Paper/cardboard mortars lose their strength and can fail when they become damp.**

Burial of Firework Mortars

- **Moisture protection** (continued)**:**
  - **When the ground is damp or when the mortars will be in the ground for more than 12 hours, paper mortars must be protected from moisture damage.**

Burial of Firework Mortars

- **Moisture protection (continued):**
  - **If there is a possibility of water seepage into the bottom of a mortar, the mortar needs to be protected.**
    - **For example, place each mortar in a plastic bag before burial.**

Burial of Firework Mortars

- **Moisture protection (continued):**
  - **All mortars must be covered when rain threatens. Usually plastic sheeting or tarps are used.**

Burial of Firework Mortars

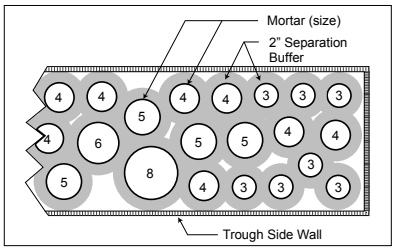
- **Inter-mortar spacing in the ground:**
  - **When buried mortars are to be fired manually, they must be separated by a distance at least equal to their ID (when practical, more separation is strongly recommended).**
  - **When mortars 6 inch or less in size are fired electrically and are not chain-fused, inter-mortar separation distance at least equal to their ID is strongly recommended, but it is not absolutely required.**

Burial of Firework Mortars

- **Mortar placement in troughs and drums:**
  - **Manual firing:**
    - **Mortars must be placed to afford the shooter a high level of protection.**
    - **Mortars must be placed with at least the greater of 2 inches or 1/2 the mortar's diameter from other mortars and the wall of the trough or drum.**

Burial of Firework Mortars

- **Mortar placement in troughs and drums:**
  - **Electrical firing:**
    - **Mortars must be at least 2 inches from the wall of the trough or drum.**



Burial of Firework Mortars

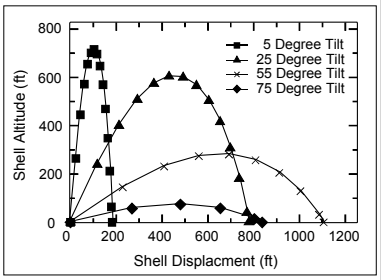
- **Requirements for burial of chain-fused mortars:**
  - **When mortars are to be chain fused, additional safety measures are required.**
  - **In the event of a mortar explosion, these measures reduce the chance that adjacent mortars will become misaligned and aerial shells will be fired in dangerous directions.**

Burial of Firework Mortars

- **Burial of chain-fused mortars (continued):**
  - **Possible additional safety measures include:**
    - **The inter-mortar distance should be at least 2 times the mortar ID. (When practical, even greater separation is strongly recommended.)**
    - **If the mortars are placed at twice the minimum separation distance to spectators, then additional inter-mortar distance is not required (i.e., a separation equaling the mortar ID is acceptable).**

Effect of Mortar Angling

- **The displacement of a shell as it reaches its apogee, and where a dud may fall, is a function of mortar tilt angle. For a typical 6-inch shell under typical conditions:**



Effect of Mortar Angling

- **The amount of down range displacement of typical dud aerial shell landing points for various mortar tilt angles are:**

Tilt Angle (degrees)	Down Range Dud Displacements by Shell Size					
	3 in.	75 mm	6 in.	150 mm	12 in.	300 mm
	ft	m	ft	m	ft	m
0	0	0	0	0	0	0
2	40	10	70	20	130	40
5	100	30	180	60	310	100
10	200	60	360	110	610	190
15	290	90	520	160	880	270
20	370	110	660	200	1130	340

Mortar Angling for Wind

- **Wind blows shells and debris off course.**

Wind Speed		Down Range Dud Displacements by Shell Size					
		3 in.	75 mm	6 in.	150 mm	12 in.	300 mm
mph	km/hr	ft	m	ft	m	ft	m
0	0	0	0	0	0	0	0
5	8	50	10	50	20	60	20
10	16	100	30	100	30	110	30
15	24	150	40	160	50	170	50
20	32	200	60	210	60	260	70
25	40	240	70	270	80	280	90

Mortar Angling for Wind

- **The wind speed of consequence is not the wind measured at ground level, but the average wind speed throughout the entire flight of the aerial shell.**
  - **Typically the winds aloft are significantly greater than those at ground level because of the interference caused by shrubs, trees, buildings, etc.**
  - **The average effective wind aloft is probably about twice that measured near ground level.**

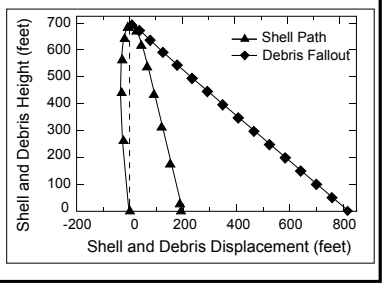
Mortar Angling for Wind

- **Displacement of dud shell points-of-fall, because of wind, is mostly independent of size and is proportional to wind speed.**
  - **To correct for wind drift, for every 5 mph of wind aloft, mortars may be tilted toward the wind by approximately →**
  - **But, NEVER angle mortars toward spectator areas.**

Aerial Shell Size		Tilt Angle
in.	mm	degrees
3	75	2
6	150	1.5
12	300	1

Mortar Angling for Wind

- **Proper mortar tilt angle can only counter the effect of wind to a limited extent. One can only correct for one of the following:**
  - **Where the shell will burst.**
  - **Where a dud will fall.**
  - **Where the heavy debris will land.**



Placement of Mortar Racks

- **The location of mortar racks, when aerial shells are <u>individually fired</u>, is the same as for buried mortars:**
  - **Mortar racks are offset from center of the display site for angled mortars.**
  - **Mortar racks are placed at the approximate center of the display site for vertical mortars.**

Placement of Mortar Racks

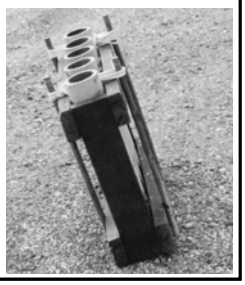
- **The location of racks for <u>chain-fused</u> shells:**
  - **If very strong (e.g., steel) racks are used, those racks may be located at the same distance as racks containing individually fired mortars.**

Placement of Mortar Racks

- **Racks for <u>chain-fused</u> shells (continued):**
  - **Typical wooden racks are sufficiently weak that they must be placed at twice the normal spectator separation distance.**

Placement of Mortar Racks

- **Physical requirements:**
  - **Racks must be rigidly braced to prevent re-alignment, especially for chain-fused shells.**



Placement of Mortar Racks

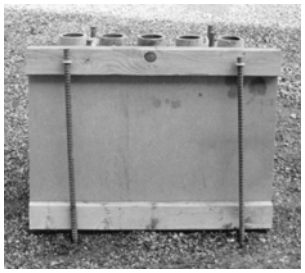
- **Physical requirements (continued):**
  - **Racks must be rigidly braced (example).**

Placement of Mortar Racks

- **Physical requirements (continued):**
  - **Racks NOT rigidly braced (bad example).**

Placement of Mortar Racks

- **When manually firing, it is recommended (not required) that racks be barricaded or sand bagged for crew protection.**

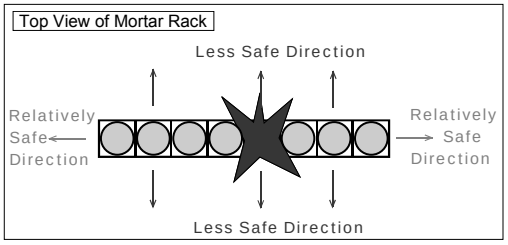


Weather and Spark Protection

- **Tarps or heavy plastic sheeting provides good weather protection, and aluminum foil gives good protection from sparks and light weight burning debris.**

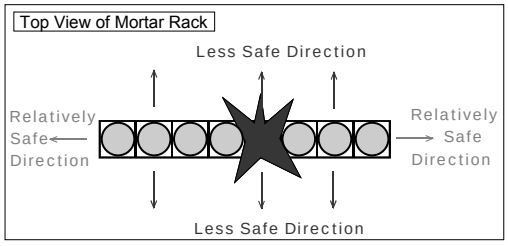
Orientation of Mortar Racks

- **If an explosion destroys a mortar rack, the mortars may aim in dangerous directions.**
  - **The remaining mortars are more likely to tip somewhat toward the sides of the rack.**



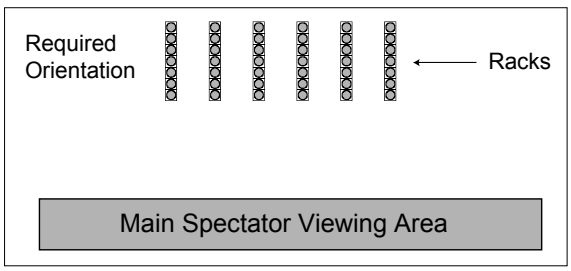
Orientation of Mortar Racks

- **If an explosion destroys a mortar rack….**
  - **If shells fire from those tipped mortars, they are more likely to be sent in directions perpendicular to the rack's orientation.**



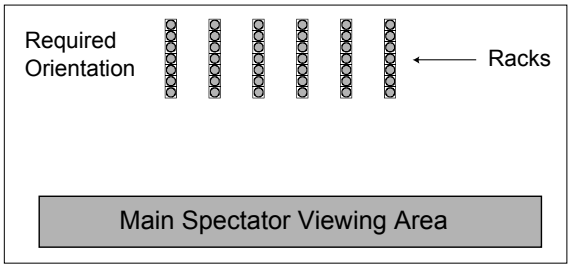
Orientation of Mortar Racks

- **Accordingly, chain-fused racks must be oriented so as to be perpendicular to the main spectator area.**



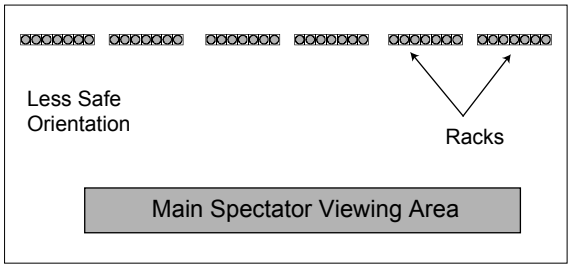
Orientation of Mortar Racks

- **The firing should start from the rack end nearest spectators, leaving those mortars empty if a mortar rack explodes.**



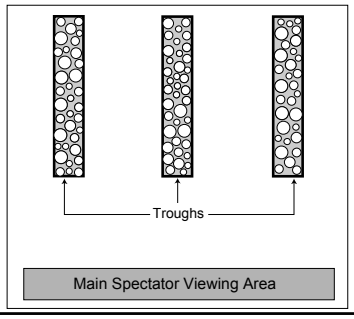
Orientation of Mortar Racks

- **Unfortunately it is relatively common to have chain-fused racks placed parallel to the main spectator area (bad example).**



Orientation of Mortar Troughs

- **In much the same way as for mortar racks, troughs should also be oriented perpendicular to the main spectator viewing area. (Fire starting from nearest spectators.)**

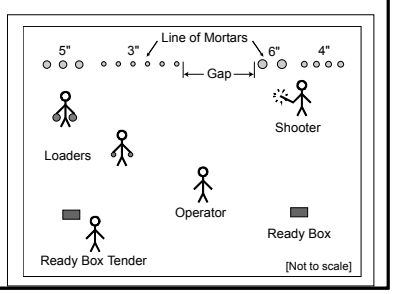


Placement of Ready Boxes

- **Location of ready boxes (storage containers for aerial shells during a display with reloading):**
  - **The ready boxes must be placed at least 25 feet upwind from mortars.**
  - **The orientation of the ready boxes must be such that the lid opens on the side away from mortars, to help avoid the accidental entry of sparks.**

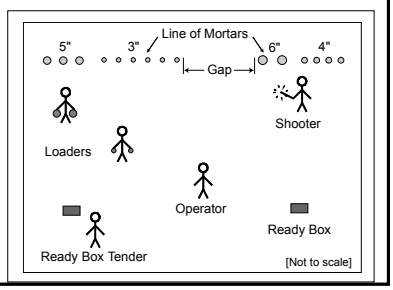
Placement of Ready Boxes

- **The number of ready boxes:**
  - **Generally, there should be at least two ready boxes, one on each side of the line of mortars.**



Placement of Ready Boxes

- **To help eliminate reloading errors, if the box contains more than one size shell, they should differ in size by more than one inch.**
  - **3- and 4-in. — NO.**
  - **3- and 5-in. — OK.**



End of Unit

Chain Fusing Techniques

- Chain fusing methods
- Preparation of finale chain fusing
- Slowing quick match burning
- Delay elements for quick match
- Making slow-burning fuse chains
- Short fusing
- Re-ignition points

Chain Fusing

- The most efficient method for firing large numbers of aerial shells in a barrage or finale is to chain their quick match shell leaders together. In this way, one ignition will cause many shells to fire sequentially.

Chain Fusing

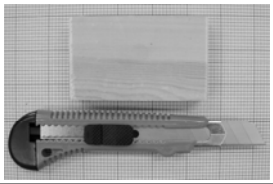
- Often aerial shells can be purchased already chain fused. At other times, it will be necessary to do the chain fusing one's self.

Chain Fusing Methods

- There are two common methods for normal firing-rate chain fusing of shells with black match as their ignition point.
- Method 1: When the aerial shell leaders are long enough, no additional fuse is necessary. In effect, each successive quick match fuse is simply inserted into the preceding shell's fuse

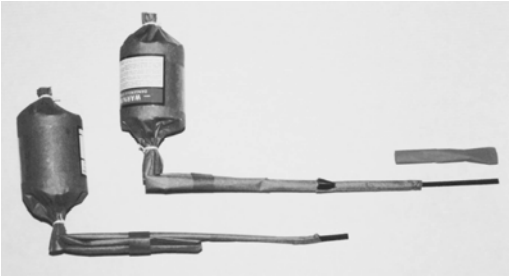
Quick Match Cutting

- CAUTION: Quick match fuse cutting must be done using a sharp knife or a sharp, anvil-type pruning shears. Because of the possibility of an ignition, have no unnecessary pyrotechnic materials in the immediate area.



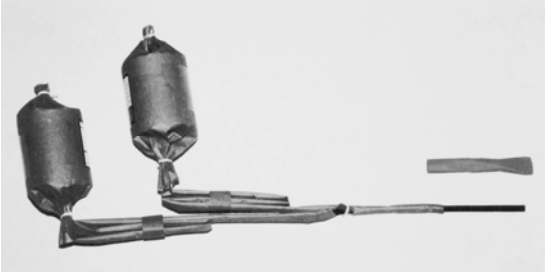
Chain Fusing Method 1

- The first shell's leader has been sliced open and the second shell's black match has been trimmed.



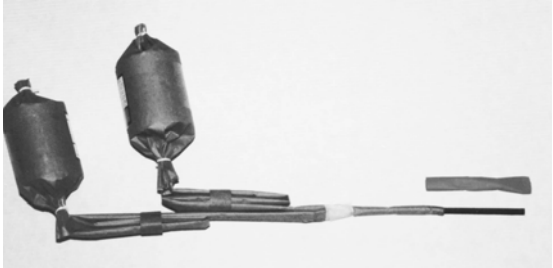
Chain Fusing Method 1

- The black match from the second shell has been inserted and tied with string onto first shell's leader.



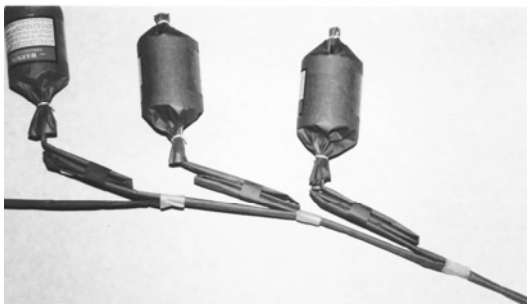
Chain Fusing Method 1

- Tape is applied to the splice to protect it from stray sparks that could cause an accidental ignition.



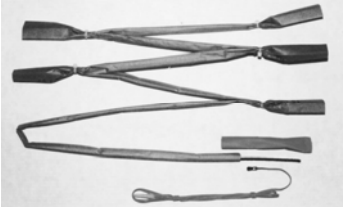
Chain Fusing Method 1

- An example of several aerial shells chained together using this method.



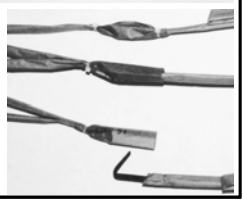
Chain Fusing Method 2

- Method 2: When the shell leaders are not long enough to use the previously described method (or as a matter of convenience), a specially made series of connecting fuses (a finale fuse chain) can be used to chain-fuse the individual shells.



Chain Fusing Method 2

- Connect shells to finale fuse chain. Expose black match, insert it into one of the "buckets" and secure the fuse with string or a small cable tie.



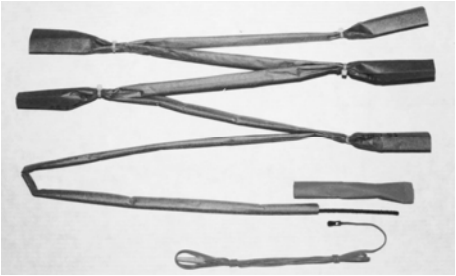
Making a Finale Fuse Chain

- Cut quick match and expose black match ends.

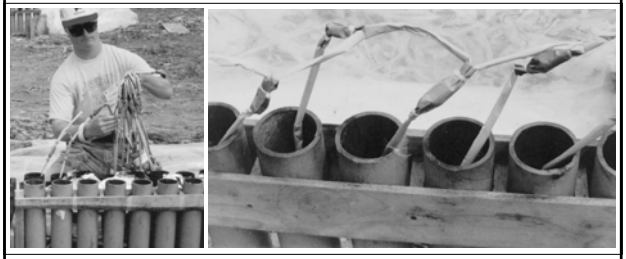
- Connect to coin wrappers.

Making a Finale Fuse Chain

- Continue until a sufficient number of attachment points (buckets) have been included in the chain.

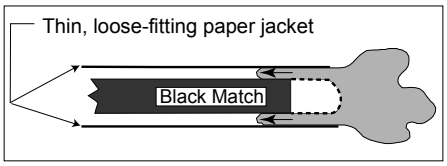


Loading Chain Fused Aerial Shells



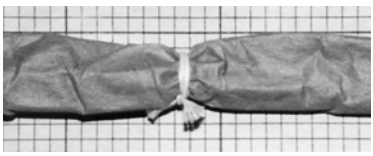
Methods of Slowing Quick Match

- To slow the firing rate of shell firings, cause short delays in the chain.
- Quick match burns rapidly because fire races down its length in the fire path between the black match and the paper wrap.



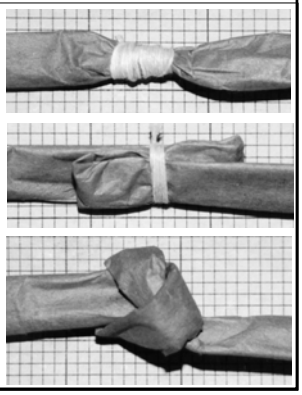
Methods of Slowing Quick Match

- Accordingly, if the fire path is tightly closed, burning of the quick match will be momentarily slowed at that point.
- As a rough guide, each time a string is tied tightly around quick match, a 1/4-second delay will be introduced when the quick match burns.



Methods of Slowing Quick Match

- Longer delays can be produced by closing off longer lengths of the fire path between the black match and the paper wrap of the quick matrch.



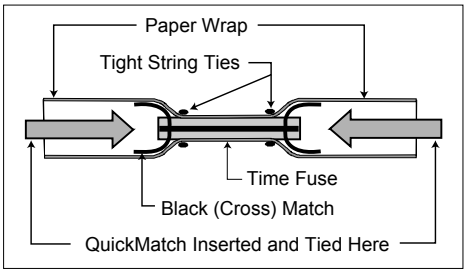
Methods of Slowing Quick Match

- Burn times were measured for 16-inch lengths of quick match using various slowing methods, see below:

Method	Burn Time at 35% Relative Humidity[a] (seconds)	Burn Time at 78% Relative Humidity[a] (seconds)
None	≡0	≡0
Single Tie	0.2	0.6
Cable Tie	0.4	1.0
Knot	0.5	1.2
"S" Tie	0.5	1.1
1/2" Long Tie	0.8	1.6

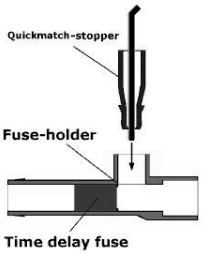
Delay Elements for Quick Match

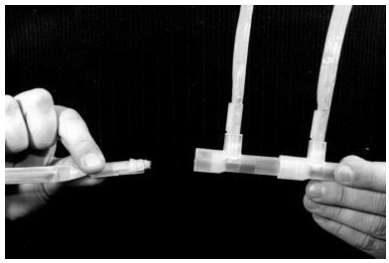
- **When long or precise delay time is needed, a delay element made using fireworks time fuse can be used.**



Pyro Clock – Time Delay Element

- **A commercially produced system can be used to provide variously timed firing of chain-fused aerial shells.**



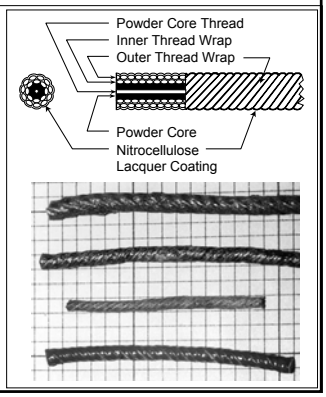


Making Slower Burning Fuse Chains

- **There are time when quick match chains burn much too fast for the intended purpose, however, it is still desired to use chain fusing.**
- **Slow burning chain fusing can be made using slower burning fuse; for example, visco fuse or plastic igniter cord can be used.**

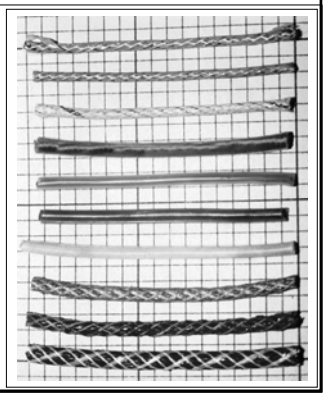
Visco (Hobby or Cannon) Fuse

- **Visco fuse is also call hobby fuse or cannon fuse, and is used on many consumer fire-work items. It has a burn rate of about 2.6 s/in.**



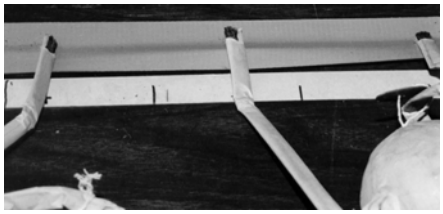
Visco (Hobby or Cannon) Fuse

- **There are a number of types of igniter cord available with varying designs and burn rates. The most com-monly available is plastic coated with a burn rate of about 1.2 sec./in.**



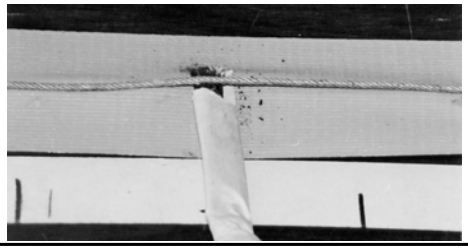
Making Slower Burning Fuse Chains

- **Lay out a wide strip of heavy adhesive tape, such as duct tape with adhesive side up. On this tape lay out a series of aerial shell leaders with about 1/2 inch of exposed black match at the ends.**



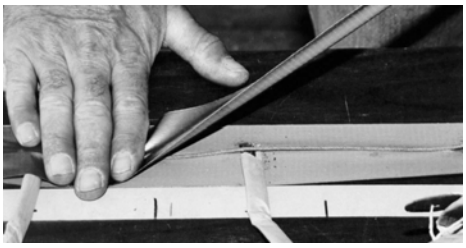
Making Slower Burning Fuse Chains

- Lay a length of visco fuse or plastic igniter cord on the tape and over the ends of the exposed black match of each shell leader.



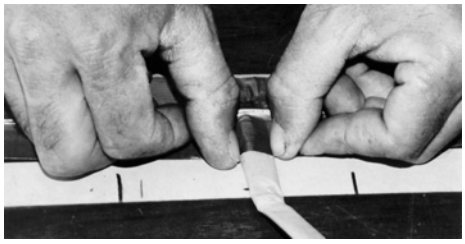
Making Slower Burning Fuse Chains

- Apply a second strip of heavy, wide adhesive tape (adhesive side down) over the first strip of tape.



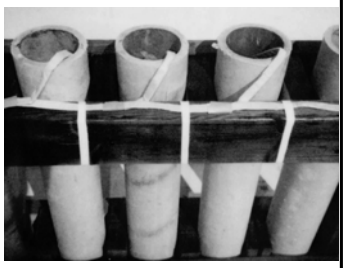
Making Slower Burning Fuse Chains

- Tightly seal all of the fuse segments between the two strips of tape.



Short Fusing

- "Short Fusing" is the term for firmly securing the chain fusing to the mortar rack. Most often this is accomplished using strapping tape or tying with string.



Short Fusing

- If a mortar explodes destroying a mortar rack, short fusing can reduce the likelihood of aerial shells accidentally continuing to fire, possibly into spectator areas.
- During normal firing, short fusing may help to assure that all the chain-fused shells will fire by making it more likely the fusing will remain intact during firing.

Short Fusing

- An example of a finale chain continuing to fire after a rack has been damaged and has fallen over and aimed at spectators.

Chain Fusing Re-Ignition Points

- Occasionally a chain fuse will fail to burn completely (generally because it was improperly made or installed.) and it may be desired to relight the chain.
- Relighting chain-fused shells is dangerous, unless done properly. Only a previously installed re-ignition point should be used, one that provides a time delay, allowing the shooter to safely retreat.

Chain Fusing Re-Ignition Points

- A re-ignition point will generally be a length of quick match at least 3 feet (1 m) long that has at least 3 inches of exposed black match covered by a safety cap. The other end of the length of quick match is connected into the fuse chain.
- As an alternative, multiple short chains could have been used, each with its own ignition point.

End of Unit

Making Repairs to Fireworks

- Most often needed repair supplies
- Specific repairs to aerial shells:
  - Shell leader safety cap
  - Black match delay element
  - Shell leader
  - Fuse loop / suspender torn or missing
  - Leaking lift powder
  - Damaged casing or water-damaged shell
- Repairs to other fireworks
  - Loose components
  - Damaged nosing

Repair of Fireworks

- Occasionally shells and other fireworks sustain minor damage during shipping or from handling on the display site.
  - Minor repairs may be made if the crew has the knowledge and the needed materials.
  - Limit repairs to those that do not require actual disassembly of the fireworks.
- Repair work should be separated by at least 200 feet from the public and at least 50 feet from any firework storage area.

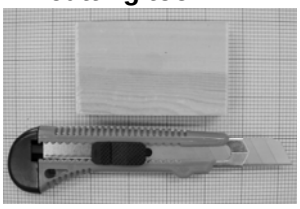
Repair Tools and Materials

- Among the most often needed repair tools and materials are:

Masking tape	Black match strands
Strapping tape	Visco (hobby) fuse
String or cord	Razor knife (or box slitter)
Construction wire	Pliers (regular and cutting)
Quick match	Scissors
Kraft paper	Fuse cutters

Appropriate Fuse Cutting Tools

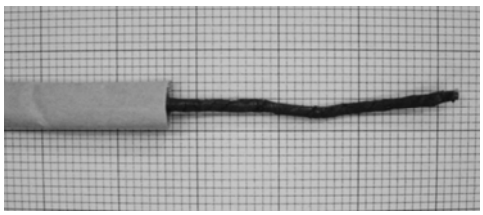
- Common methods use a razor knife and a block of wood or a razor knife / anvil cutting tool .



- ALWAYS anticipate that cutting a fuse could cause its ignition.

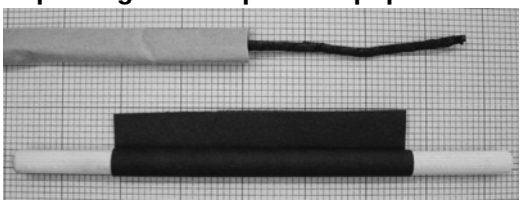
Missing Shell Leader Safety Cap

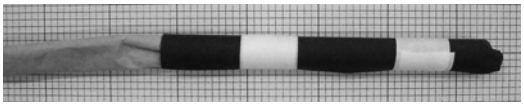
- Problem: The black match is exposed and any stray spark could prematurely ignite the firework.



Missing Shell Leader Safety Cap

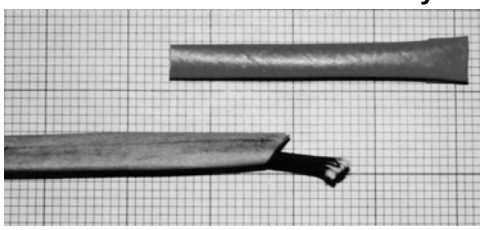
- Solution: Make and install a new safety cap using a small piece of paper.





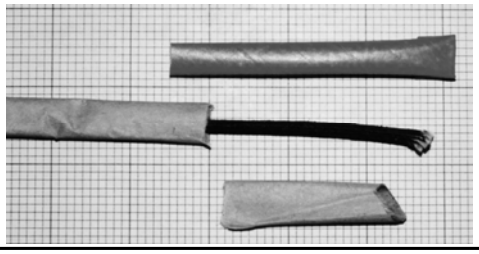
Short Black Match Delay on Shell Leader

- **Problem: If the exposed black match delay element is short (≤3 inches) the time between its ignition and the shell firing will be too short for shooter safety.**



Short Black Match Delay on Shell Leader

- **Solution A: If the leader is long enough to extend 6 inches out of the mortar, tear off additional paper covering from the shell leader to expose more black match.**

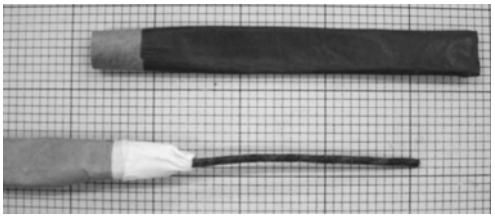


Short Black Match Delay on Shell Leader

- **Solution B: If the leader is not sufficiently long, then splice on a short length of quick match with a proper length of black match exposed on its end.** (Such splicing is shown later.) **Then reinstall the safety cap over the fuse end.**

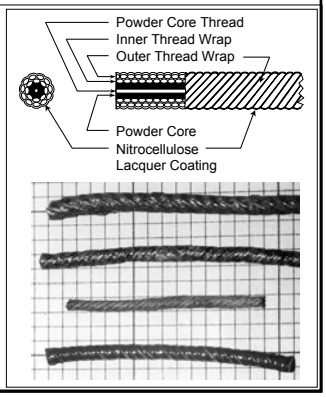
Short Black Match Delay on Shell Leader

- **Solution C: Cut-off the black match and add a length of visco fuse by inserting the fuse about 1 inch into the end of the shell leader and wrapping the joint with tape.**



Visco (Hobby or Cannon) Fuse

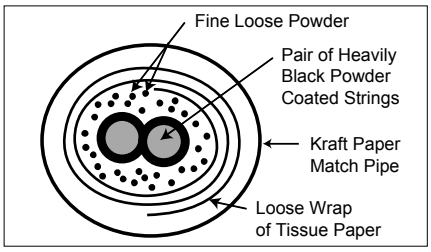
- **Visco fuse is also call hobby fuse or cannon fuse, and is used on many consumer firework items.**



WARNING: Fuse Look-Alike Problem

- **A type of shell leader appears to have a black-match-like fuse inside it, however, the black-match fuse actually performs radically different.**
- **Black match typically burns at about 1 inch per second, the similar appearing fuse burns nearly as fast as quick match (>10 ft. per second). Thus, even exposing several inches of this of fuse will provide essentially no delay after igniting it.**

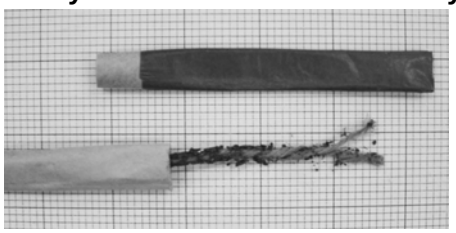
WARNING: Fuse Look-Alike Problem



- **If this type of fuse is encountered, the only way to provide a delay is to add a length of standard black match or visco fuse to the leader for a delay element.**

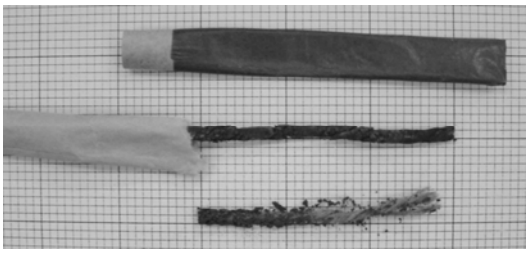
Damaged Black Match Delay Element

- **Problem: If the black match delay element is seriously damaged, the fuse may fail to take fire, burn completely, or alternatively the delay could be too short for safety.**



Damaged Black Match Delay Element

- **Solution: Cut-off the damaged black match and follow solutions A, B or C.** (Described previously.)

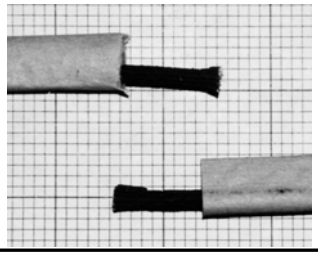


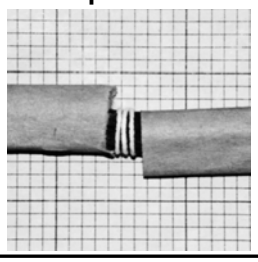
Shell Leader Is Too Short

- **Problem: A short shell leader may not extend a safe distance (6 inches) out of the mortar.**
  - **It is possible that the end of the short shell leader will slip down into the mortar after the shell is loaded, making it impossible to safely ignite the shell leader.**

Shell Leader Is Too Short

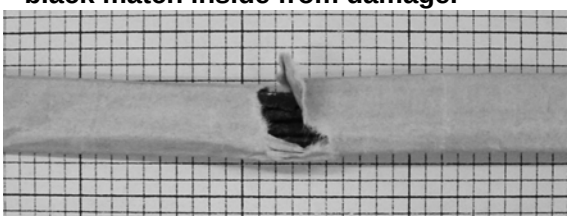
- **Solution: Add a short length of quick match. Expose black match on the ends, insert the match ends into the paper, tie with string, and cover with tape.**





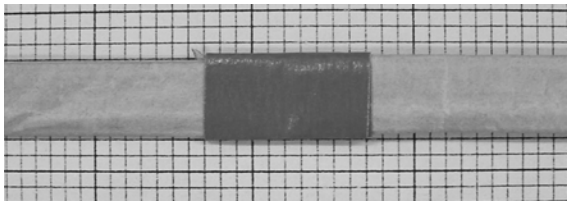
Tear in Quick Match Paper Wrap

- **Problem: A tear in the paper of quick match exposes some black match, which could be ignited by a stray spark. Also the paper provides strength and protects the black match inside from damage.**



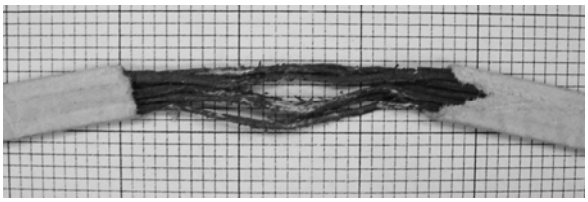
Tear in Quick Match Paper Wrap

- **Solution: If the black match has not been seriously damaged, wrap a short length of masking tape around the tear to protect and strengthen the fuse.**



Seriously Damaged Shell Leader

- **Problem: If the shell leader is seriously damaged, it may fail to function properly. Thus a hangfire, a misfire or an accidental ignition from a stray spark may result when attempting to fire the aerial shell.**



Seriously Damaged Shell Leader

- **Solution: Cut out the damaged portion, and do one of the following:**
  - **A) If a sufficient length of leader remains to extend about 6 inches out of the end of the mortar, simply splice the two fuse pieces back together.** (Described earlier.)
  - **B) If an insufficient length of leader remains to extend about 6 inches out of the end of the mortar, splice in an appropriate length of additional quick match.** (Described earlier.)

Fuse Loop / Suspender Torn or Missing

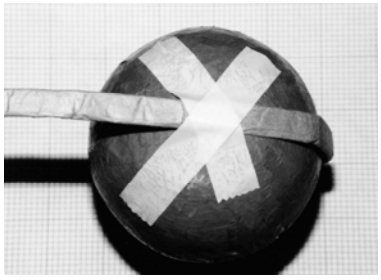
- **The fuse loop (suspender) is generally a loop of cord attached to the top of the shell through which the shell leader passes. Thus, when the shell is held by the leader for lowering into the mortar, the shell will be oriented properly (i.e., with the lift charge on the bottom).**

Fuse Loop / Suspender Torn or Missing

- **Problem: If the fuse loop is missing or torn and the shell is held by the shell leader, it could orient itself upside down. If the shell is loaded up side down, the shell will not leave the mortar when fired and will explode in the mortar after a few seconds delay.**

Fuse Loop / Suspender Torn or Missing

- **Solution: Using strong tape (e.g., strapping tape), tightly secure the shell leader to the top of the aerial shell.**



Leaking or Leaked Lift Charge

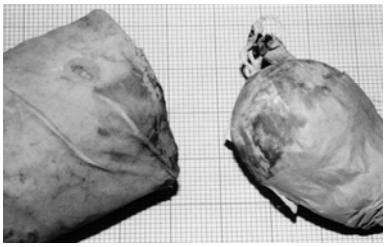
- **Problem: When an aerial shell has lost a significant amount of its lift charge, the shell will be a low break when fired. If the shell has lost most of its lift charge, the shell will likely explode on the ground in the area of the mortar, or possibly while still within the mortar.**

Leaking or Leaked Lift Charge

- **Solution: A field repair should not be attempted, and the aerial shell must not be used. After the display:**
  - **If practical, the aerial shell should be returned for repair where the proper equipment and supplies are available.**
  - **If the aerial shell cannot be returned for repair, it should be disposed of as per the supplier's instructions.**

Shell Damaged or Has Gotten Wet

- **Problem: When an aerial shell is used that has been damaged or has gotten wet, it may malfunction in any of a number of unpredictable ways.**



Shell Damaged or Has Gotten Wet

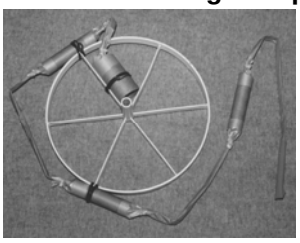
- **Solution: A field repair should not be attempted and the shell must not be used.**
  - **After the display, the damaged aerial shell should be returned to the supplier or disposed of as per the supplier's instructions.**

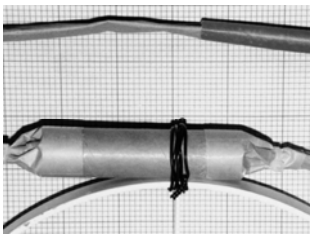
Repair of Other Fireworks

- **When the damage to other types of fireworks is to the quick match, repairs such as suggested for shell leaders may be made as described previously.**

Loosened Components

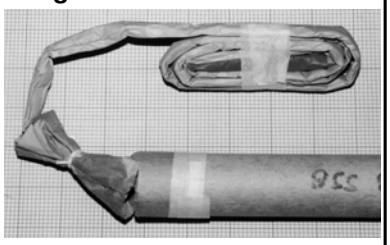
- **A loosened component from a wheel or other set piece may be re-attached using string, strapping tape or wire depending on the strength required.**





Damaged Nosing

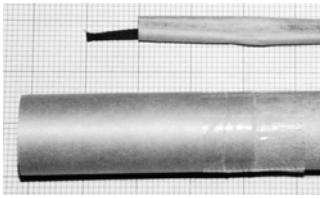
- When the nosing paper wrap has become torn, it should be removed and replaced, to provide a strong attachment for its fuse and to keep stray sparks from igniting the item prematurely.



Damaged Nosing

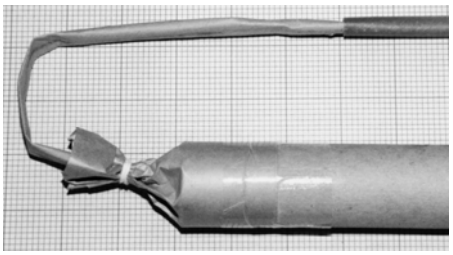
- First remove the old (torn) nosing.

- Then attach a new paper nosing using tape.



Damaged Nosing

- Then secure the quick match fusing into the paper nosing using tightly tied string.



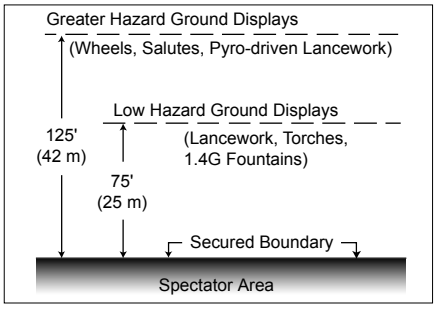
End of Unit

Setup Ground and Low-Level Fireworks

- Separation distances for ground items
- Setup of fireworks on poles
  - Guy wire safety tips
- Setup and separation distances for comets, mines and low-level aerial items
- Other considerations
  - Accidental Ignition
  - Moisture protection
  - Iron wire tie example

Separation Distance for Ground Items

- The minimum separation distance requirements of NFPA-1123.

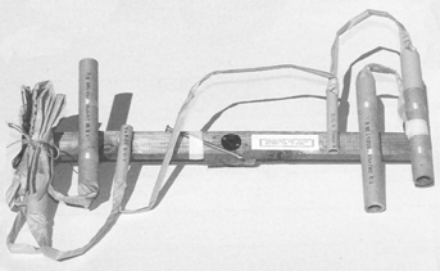


Separation Distance for Ground Items

- Actual separation distances used must consider the potential hazard of each item in the event of its possible malfunction.
- When a display includes some proximate audience pyrotechnic items, which are set-up and fired in full accordance with NFPA-1126, the reduced separation distances as prescribed in NFPA-1126 may be used for those proximate audience items.

Setup of Fireworks on Poles

- Many ground display items require mounting and erection, e.g., wheels need to be attached to a pole or post.



Setup of Fireworks on Poles

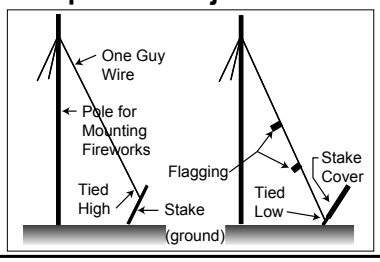
- The attachment of a wheel must be secure; the wheel must not separate from the pole during use or if it malfunctions.

Setup of Fireworks on Poles

- The pole must be sufficiently secure such that it stays erected during use.
  - Larger firework items will need to have guy wires or ropes (each tied to stakes in the ground) to keep the pole erect.

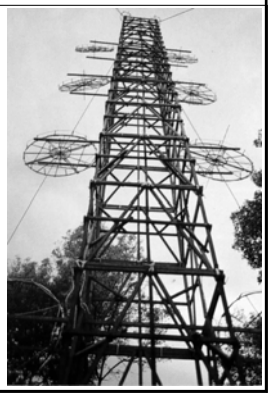
Guy Wire Safety Tips

- Attachment to stakes - near ground level.
- Flagging for added visibility (night).
- Stake covers – helps avoid injuries and increases visibility.



Massively Large Ground Display

- Massively large Castillos, popular in Latin America, have their own unique engineering requirements.



Massively Large Lance-Work

- This large approximately 25-foot (8-m) square lance-work is to be hoisted into place and supported using a tall crane

Separation Distances - Comets & Mines

- Minimum mortar-to-spectator separation distances for comets and mines:
  - The basic requirement is for 35 feet per inch of diameter, or half that required for aerial shells.
  - It is thought that comets and mines larger than 6-inch are not safe.

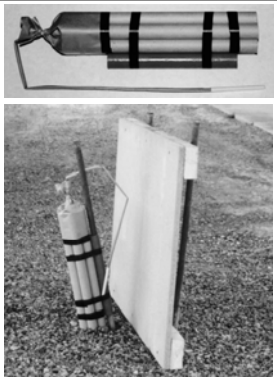
Size (in.)	Vertical Mortars (ft)	Angled Mortars (ft)
≤1	38	38
1.5	53	38
2	70	48
2.5	88	58
3	105	70
4	140	95
5	175	115
6	210	140

Setup of Low Level Aerial Items

- When possible, low-level aerial fireworks (small Roman candles, comets, mines and consumer multi-shot cakes) should be angled so that their effects are propelled away from spectator areas.
  - When the separation distance is greater than the maximum range of the item, angling is not useful for safety.

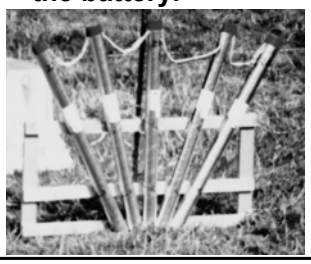
Staked Roman Candle Battery

- A Roman candle battery is securely staked and angled away from spectators. A protective barrier is placed on the spectator side of the battery.



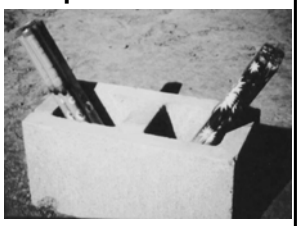
Barricading of Roman Candle Batteries

- A Roman candle battery attached to a wooden frame and a mortar rack. The frame should be on the spectator side of the battery.



Poorly Secured Roman Candle Batteries

- Roman candle batteries dangerously secured into position and without barricading for spectator protection.

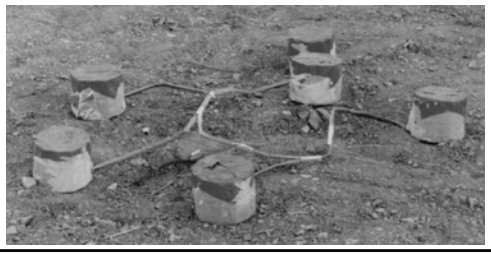


Placement Methods for Cakes

- A cake item placed into a bucket with sand on the bottom for weight is a good placement method.

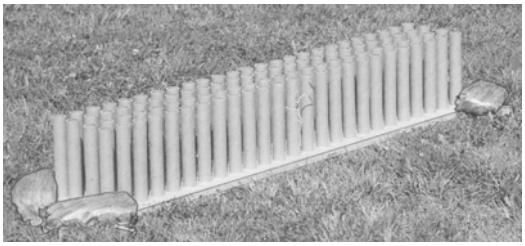
Placement Methods for Cakes

- Although barricading is not required (NFPA), it is strongly recommended if the items are at or near the minimum spectator separation distance.



Small Caliber Barrage Racks

- Racks of small caliber items must be well secured, such that they will not be repositioned during use or malfunction (legs, sand bags, staking, barricades).



Accidental Ignition Considerations

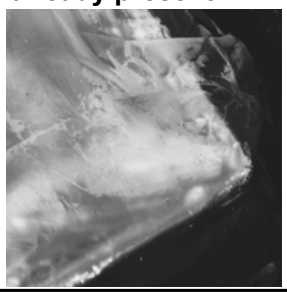
- In placing ground and low-level aerial fireworks, minimize the chances of accidental ignitions.
- Help avoid accidental ignition of shells:
  - Ground and low-level aerial fireworks should not be located in the immediate area where mortars have been loaded with shells.
  - Most importantly, sparks from ground displays must not be produced near ready boxes or where shell loading is occurring.

Accidental Ignition Considerations

- To help avoid ignition of ground items:
  - Separate ground displays by at least 25 feet.
  - Locate ground displays reasonably far from the fallout from high-level aerial displays.
  - If necessary, ground displays can be protected using tarps or aluminum foil.
- To help avoid ground and other fires:
  - Try to remove the combustible materials.
  - Wet down area if combustibles remain.

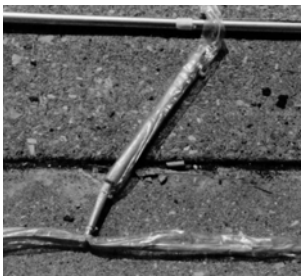
Moisture Protection

- Plastic bags or sheeting can be used to protect items from external moisture but can trap in moisture already present.

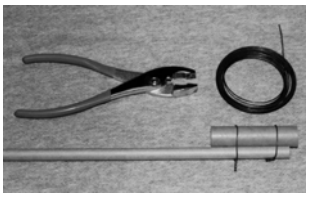
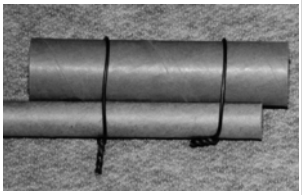
Moisture Protection

- Very thin plastic tubing can be used to protect quick match and small items like gerbs and Niagara falls tubes from moisture.

Iron Wire Tie Example

- A pliers can cut and twist iron wire to help secure ground display items to stakes.
  - The twisted ends can cause injury. Bend the exposed ends over or cover them with tape.

End of Unit

Manual Fireworks Display Procedures

- Operator responsibilities and crew unit
- Shell loading and firing
- Ready box tending
- Crowd control monitors
- Show interruptions and after the show
- Other topics:
  - Barge and roof-top displays
  - Salutes
  - Preloaded manually fired displays

Display Operator's Responsibilities

- Display Operator: The person with overall responsibility for safety, and the setting up, discharge and tear down of an outdoor fireworks display.
- The operator's responsibility:
  - With regard to the Public:
    - No single failure of fireworks or equipment can be allowed to injure a member of the public.

Display Operator's Responsibilities

- The operator's responsibility:
  - With regard to the Crew:
    - Training: Tell them the correct way and WHY.
    - Crew Size: Do not have too many or too few.

Display Operator's Responsibilities

- Consider why a Sponsor is willing to pay for a display.
  - Good public relations / favorable press coverage
- With regard to the Sponsor and the Display Company:
  - First and Foremost: A Safe Show.
  - Second: A Great Performance.

Display Operator's Responsibilities

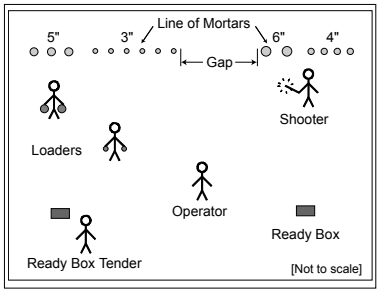
- Operator Participation:
  - Before and after the display — Oversee and check on the proper completion of all work.
  - During the display — Monitor safety and crew performance and take all needed corrective measures.

Display Operator's Responsibilities

- Assistant: A person who works under the direct supervision of the Display Operator.
- Assistant's responsibility:
  - When in doubt – ASK.
  - When not in doubt – THINK TWICE.
  - Be ever mindful of your own safety as well as that of spectators and the rest of the crew.

Firing Crew Personnel Assignments

- The basic firing crew unit for a manually-fired display with reloading:
  - 1 Shooter,
  - 2 Shell loaders,
  - 1 Ready box tender,
  - 0 Mortar cleaners

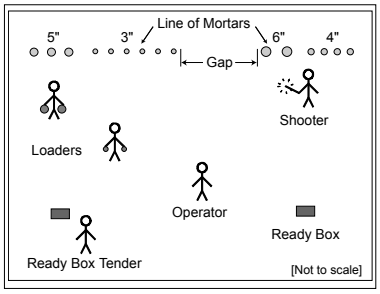


Display Operator

- The operator is NOT part of the basic firing crew unit. During the display, the operator:
  - Monitors public safety & crew performance.
  - Controls the activity and corrects problems.
  - May act as the safety spotter.
  - Should not be the shooter (except possibly on the very smallest of displays).
    - The shooter will be much too busy doing the operator's main job — monitoring SAFETY!

Firing Crew Personnel Assignments

- Loading and shooting must be separated by taking place on opposite sides of the mortar line.
  - A gap of at least 25 feet between loading and firing is recommended.

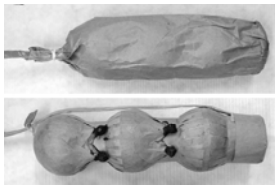


Maximum Safe Firing Rate

- The maximum safe firing rate for one shooter is no more than about 12 shells per minute, because of the amount of time required to safely perform the task.
  - Approach the mortar, remove the safety cap and light the fuse ($\gtrsim$2 sec.).
  - Fuse delay before the shell fires ($\gtrsim$3 sec.).
  - Thus the total time is $\gtrsim$5 seconds per aerial shell firing or $\lesssim$12 shells fired per minute.

Maximum Safe Firing Rate

- If a greater firing rate is needed:
  - Use chain-fused or multi-break shells.



  - Use a second firing crew.
    - Note that this will also require using a second set of mortars located a safe distance (>25 feet) away from the first set of mortars and crew.

Shell Loading – General Guidance

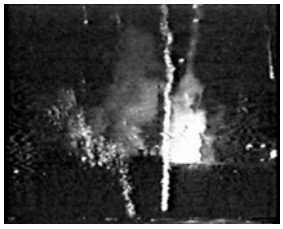
- Shell reloading poses added risks and is discouraged. (Discussed further later.)
- Carry aerial shells by their body, not by their fuse.
- Never place any body parts over a mortar.
- Smaller shells are lowered into the mortar by holding their leader fuse.

Shell Loading - General Guidance

- Shells (larger than 6-inches) are lowered into the mortar using their lowering cord.

Shell Loading - General Guidance

- Make sure the aerial shells are properly seated near the bottom of the mortars.
- Do not remove the safety caps from the shell leader. (Video)

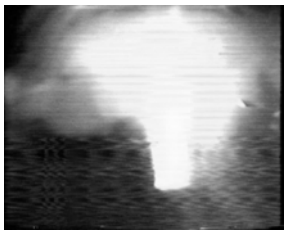


Shell Loading - General Guidance

- Try to keep one's back toward the loaded mortars and the shooter.
- Try to keep at least 25 feet away from the shooter and the discharging fireworks.
- Try to protect unloaded shells from ignition (stray sparks and burning debris).
- Avoid loading errors by not loading several different shell sizes.

Shell Loading - General Guidance

- If an aerial shell becomes stuck part way down the mortar:
  - Treat this situation as if it were a misfire and abandon use of that mortar.
  - Never force a shell into the mortar. (Video)



Shell Loading - General Guidance

- Chain-fused aerial shells must not be reloaded during a display.
- If much debris has collected in the mortar, only then clean that mortar, and only do so when absolutely certain the previous shell has fired from that mortar. (Video)

Shell Loading - Preparation

- Prepare the shell leader for loading:
  - Tear the band of paper securing the bundle of shell leader.
  - Completely unwrap the shell leader, leaving the safety cap in place.

Shell Loading - Method 1

- Approach the mortar holding the aerial shell by the leader fuse (on large caliber shells use the lowering cord – or hold the shell by its body)

Shell Loading - Method 1

- Swing the aerial shell slightly out over the top of the mortar and lower the shell toward the mortar.

Shell Loading - Method 1

- Catch the aerial shell in the top edge of the mortar.

Shell Loading - Method 1

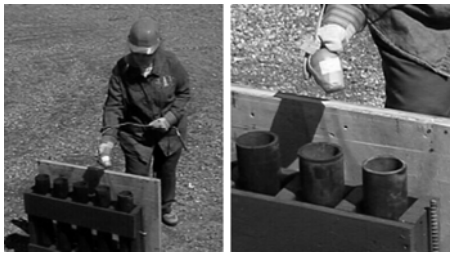
- Lower the aerial shell into the mortar. (The shell should slide freely to the bottom of the mortar.)

Shell Loading - Method 1

- Video Demonstration:

Shell Loading - Method 2

- Hold the aerial shell, instead of the shell leader (or lowering cord), and move the shell toward the mortar.



Shell Loading - Method 2

- Taking care not to have one's hand directly over the mortar, set the bottom of the shell on the edge of the mortar and lower the shell as previously described.


Shell Loading - Method 2

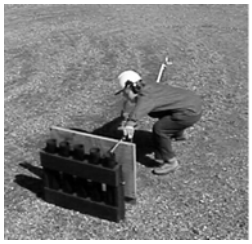
- Video Demonstration:

Shell Firing – Method

- Approach the already loaded mortar with a lighted fusee on an extender held away from the mortar.


Shell Firing – Method

- Reach forward, extending one's free hand and remove the safety cap on the shell leader fuse.




Shell Firing – Method

- Step back and rotate to bring the fusee on its extender forward.


Shell Firing – Method

- Keeping low, ignite the very tip of the delay element on the end of the shell leader.


Shell Firing – Method

- Immediately turn away, take another step, and crouch down as the delay element on the aerial shell leader fuse burns.


Shell Firing – Method

- Maintain the low-crouch position until the aerial shell fires. Only then is it safe to rise and prepare to fire another shell.


Shell Firing – Method

- Video Demonstration:

Shell Firing – General Guidance

- Make sure no body part is ever placed over the mortar opening.
- Only attempt to accomplish a single shell ignition on each approach to the mortar line.
  - Attempting more than one ignition will prevent the shooter from taking the proper position when the first aerial shell fires and may preclude detecting a hangfire if it occurs.

Shell Firing – General Guidance

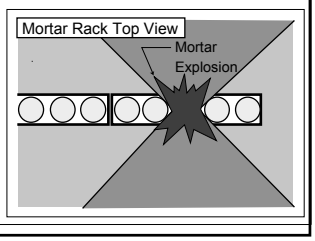
- Control the situation if a hangfire or misfire occurs.
  - Wait several extra seconds for the shell to fire.
  - If the aerial shell still does not fire, mark that mortar as a warning so that it will not be reloaded or reused during the display.
  - Verbally warn the rest of the crew and the operator that a hangfire or misfire has occurred and that the mortar has been marked to prevent its future use.

Shell Firing – General Guidance

- For chain-fused aerial shells:
  - Never remain in the immediate area after ignition. Retreat at least 25 feet.
  - If re-ignition is necessary, only use a pre-installed re-ignition point, which will provide the time needed to retreat safely.
- Rarely, if ever, should the operator act as the shooter. The shooter will be much too busy firing aerial shells to properly monitor overall safety.

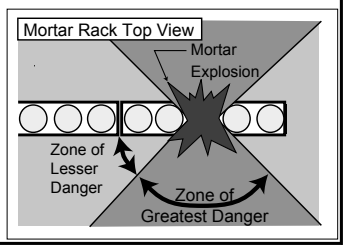
Firing Crew Protection

- When manually firing from unbarricaded mortars, employ other measures that limit exposure in the event of a malfunction.
  - In the event of a mortar explosion in a rack, the majority of the most dangerous debris is likely to be projected to the side of the rack.



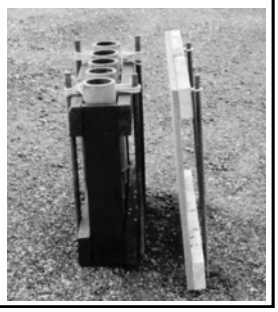
Firing Crew Protection

- When manually firing from unbarricaded mortars, ….
  - Some protection is provided by retreating along the rack's length into the "Zone of Lesser Danger".
    - Proper defensive posture is still appropriate.



Firing Crew Protection

- When firing manually (Continued)
  - It is preferred that racks be barricaded or sand bagged for crew protection from fragments from an exploding shell and mortar, as well as parts of the rack.

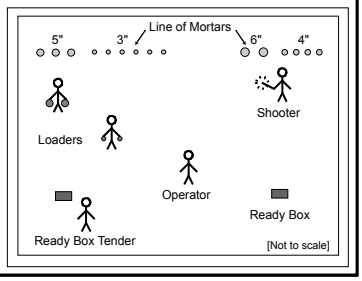


Firing Crew Protection

- When firing manually (Continued)
  - When firing chain-fused racks, the shooter should retire at least 25 feet from the racks.
  - The use of proper clothing and personal protection equipment is required but cannot be relied upon for complete crew protection.

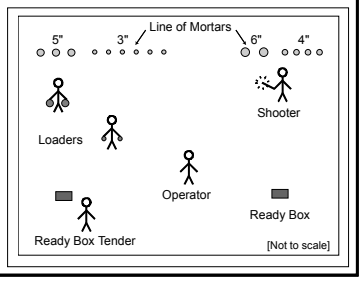
Firing Crew Protection

- The safety of other crew members.
  - A reasonable level of protection is provided to the loader, when loading is occurring some distance from where mortars are being fired. A distance of at least 25 feet is preferred.

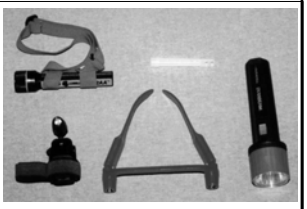


Firing Crew Protection

- The safety of other crew members.
  - A reasonable level of protection is provided to the ready box tender and stored fireworks, by placing them at least 25 feet <u>up wind</u> from where firing is occurring.

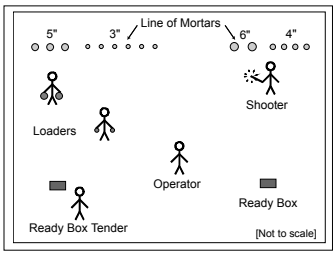


Ready Box Tending



- Use only artificial light (e.g., flash lights or chemical light sticks).
- Only open ready box lid when it is necessary and when there are no sparks in the immediate area.

Ready Box Tending



- To help avoid loading errors, take care to give the correct size shells to each loader.
- Watch for changes in ground level wind direction because this may require relocating the ready boxes.

Aerial Shell Spotting

- Closely watch the first few shells (to judge whether there has been proper angling of the mortars).
- Monitor that debris is falling out safely.
- Watch for and count dud shells.
- Watch for changes in winds aloft.
- Inform the operator if any problems are observed. (Spotting is often performed by the Operator.)

Crowd Control Monitors

- Take all reasonable efforts to maintain crowd control by keeping unauthorized people out of the display site.
- Communicate to operator if there is loss of control. Generally this will require having a radio, cell phone or a signal light of some type.

Crowd Control Monitors

- It is useful to identify the control monitors as a display official.
- Crowd control must be maintained after the display, until the operator has declared the area safe. (This can take an hour or more.)

Show Interruptions

- Decide in advance when one must interrupt the show. For example, when:
  - It is necessary to re-angle mortars because aerial shells are breaking over the crowd or debris is falling into spectator areas.
  - There is a loss of crowd control.
  - There are serious crew errors or injuries.
  - There are shell performance problems.
  - There are weather problems (e.g., a wind shift or excessive wind speed).

Show Interruptions

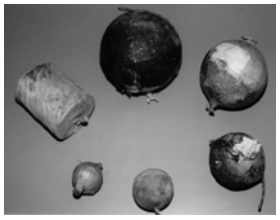
- Stopping to fix a problem will detract from the overall performance less than many operators think, especially if the interruption occurs early in the display or when the audience can be told the reason for the delay.
- Avoid the "Show Must Go On" Syndrome. This is where an operator ignores safety and foolishly continues a display for the sake of a better performance.

After the Show

- Maintain site security until the operator declares the display site safe (i.e., the site is known to be free of live fireworks).
- After the display, assume that misfires and dud shells are present.
- Allow a "cool-down" period before searching for and handling duds and misfires.

After the Show

- Search for known and UNKNOWN duds.



After the Show

- Search for known and UNKNOWN duds.
  - If chain-fused shells were fired, it must be assumed that there may be dud shells even if none were observed during the display.
  - Handle duds properly:
    - Wait at least 15 minutes before approaching.
    - Douse the dud shell with water.
    - Wait at least 5 minutes longer.
    - Remove dud with as little direct contact as possible.

After the Show

- After a cool-down period of at least 15 minutes, check all mortars for misfires.
  - Typically a stick with a handle to the side is used, allowing probing for unfired shells without placing one's hand over the mortar.
  - Handle misfires properly:
    - Fill the mortar partly with water.
    - Wait at least 5 minutes longer.
    - Remove the mortar and dump out the shell, taking care to never have any body part over the mortar.

The Next Day

- Recheck the site for dud shells and components.
  - This is always a very good idea, and it must be done when one cannot do a completely thorough inspection with powerful area lighting at night after the show.
  - This recheck should occur at first light.
  - This recheck should not be the sponsor's responsibility, unless the sponsor agrees and has the knowledge to properly (safely) perform the task.

The Next Day

- **Duds, misfires and unused fireworks.**
  - **It is preferred that duds, misfires and unused fireworks be returned to the display company.**
  - **These fireworks must be properly stored and transported.**
  - **Only if necessary, dispose of them according to the supplier's instruction.**
    - **Burial is definitely not acceptable.**

Barge and Roof-Top Displays

- **Special requirements** (Review NFPA)**:**
  - **Reloading is not allowed during a display.**
  - **No shells >6 inch can be manually fired.**
  - **No multi-break shells can be manually fired.**
  - **A barrier is required for non-firing personnel.**
  - **There are special egress requirements.**
  - **Crew must use personal floatation devices.**
  - **If both manual and electrical firing, they must be separated by at least 75 feet.**

Requirements for Firing Salutes

- **Salutes contain salute powder and produce a loud report when they explode.**

Requirements for Firing Salutes

- **Aerial salute maximum allowed with limited firing restrictions is 3 inch.**
  - **They must be fired from non-metal mortars.**
  - **They must be fired remotely or with an additional 5-second delay.**
  - **They must be pre-loaded into mortars.**

Requirements for Firing Salutes

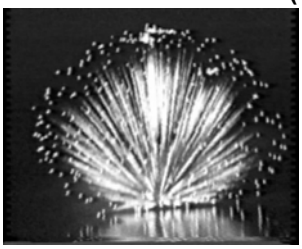
- **Aerial salute maximum allowed with greater firing restrictions is 5 inch.**
  - **All of the requirements for ≤ 3inch salutes must be met.**
  - **Mortars must be individually supported and separated from other mortars by 10 times their diameter.**
  - **They must only be used by licensed display operators or companies.**

Requirements for Firing Salutes

- **Aerial salute maximum allowed with multi-break bottom-shot is 5 inch.**
  - **All of the requirements for ≤ 5inch salutes must be met except that steel mortars may be used.**
  - **Only the bottom shot can exceed 3 inches and must not exceed 5 inches.**

Preloaded Manually Fired Displays

- **Manual firing exposes the shooter to hazards; however, reloading of shells during the display poses a far greater risk to the entire crew! (Video)**



Preloaded Manually Fired Displays

- **Reloading is hazardous:**
  - **The storage of shells in the immediate area of fire and sparks poses an explosion hazard.**
  - **The added people in the discharge area are exposed to the hazards during the display.**
  - **The handling of explosives in the dark while rushed makes accidents more likely.**

Preloaded Manually Fired Displays

- **Preloading of all aerial shells is greatly preferred.**
  - **It requires more equipment and more setup time; however, it eliminates approximately 80% of the most serious crew injuries during a display!**

End of Unit

Accident Analyses

- Display fireworks are not unreasonably dangerous when they are properly used.
- Most fireworks accidents are the result of carelessness, misuse or failure to follow regulations.
- Each year spectators and crew members are needlessly injured or killed because of failures to recognize and take seriously the potential danger of fireworks.

Accident Analyses

- Format for discussion:
  - I will describe the situation in regard to an accident.
  - We will watch a short video clip.
  - You will tell me what went wrong and how it might have been avoided.

Accident Analyses

- (1) A weak breaking aerial shell falls into the finale racks during a display.

Video Clip:

Accident Analyses

- What was the likely problem here and how might it have been avoided?
  - What about the layout chosen for the display?
  - What about the likely quality of the finale racks and their stability?

Accident Analyses

- (2) A muzzle break occurs during the course of a display fired from a barge.

Video Clip:

Accident Analyses

- What was the likely problem here and how might it have been avoided? What about the location of the ready box?
  - What about the orientation of lid of the ready box?
  - Is it possible the lid of the ready box was left open?
    - If so, how might this have been avoided?

Accident Analyses

- (3) A novice crew member was assigned the responsibility to clean mortars between firings.

Video Clip:

Accident Analyses

- What was the likely problem here and how might it have been avoided?
  - Is it necessary to clean mortars between each firing?
  - Whose responsibility is it to inform the crew if there is a hang fire?
  - Is it reasonable to expect a mortar cleaner to monitor firing closely enough to detect a hang fire?

Accident Analyses

- (4) Although staged for another purpose, on occasion display fireworks are transported in passenger vehicles.

Video Clip:

Accident Analyses

- What was the likely problem here and how might it have been avoided?
  - What are some of the requirements for transporting hazardous materials?
  - What might be done to provide greater safety for the driver?

Accident Analyses

- (5) A display is being fired from the roof of a building.

Video Clip:

Accident Analyses

- What was the likely problem here and how might it have been avoided?
  - What is at least one potential problem with doing a display from a roof top?
  - What are some of the potential problems with ready boxes?

Accident Analyses

- **(6) During a display a shell becomes stuck part way down a mortar.**

Video Clip:

Accident Analyses

- **What was the likely problem here and how might it have been avoided?**
  - **What is the proper procedure for handling a shell that has become stuck part way down a mortar?**

Accident Analyses

- **(7) A display is fired with a separation distance less than the minimum required by the NFPA.**

Video Clip:

Accident Analyses

- **What was the likely problem here and how might it have been avoided?**
- **If the NFPA minimum separation distances are used, is that a guarantee that such an accident will not occur?**

Accident Analyses

- **(8) Canvas tarps are used to cover the shells to be used in a display.**

Video Clip:

Accident Analyses

- **What was the likely problem here and how might it have been avoided?**
- **No one was injured in this incident. Why do you think that was?**

Accident Analyses

- (9) An example of poor manual firing technique.

Video Clip:

Accident Analyses

- What are the errors the shooter is committing?

Accident Analyses

- (10) Two examples of muzzle break shell malfunctions.

Video Clip:

Accident Analyses

- What measures might the crew have taken to limit the chances of their injury?
- No one was injured in the initial explosions, but were injured shortly after; what do you think the problem was and how might it have been avoided?

Accident Analyses

- (11) Another example of poor shooting technique.

Video Clip:

Accident Analyses

- What are the error the shooter is committing?
  - What are some of the possible ramifications of this potential problem?

Accident Analyses

- (12) An example of a finale rack explosion.

Video Clip:

Accident Analyses

- What are some of the potential ways in which such a malfunction could be problematic?
- What are some things that might be done to limit the chances of this happening, and to limit the possibility of an injury if it does happen?

Accident Analyses

- (13) An example of a problem caused by a low breaking shell.

Video Clip:

Accident Analyses

- What was the likely problems here and how might it have been avoided?

Accident Analyses

- (14) Examples of mortar explosions.

Video Clip:

Accident Analyses

- What are some of the things that might be done to reduce the chances of a mortar explosion?
- What are some of the measures to limit the chances of injury in the event of a mortar explosion?

Accident Analyses

- (15) An example of a shell explosion in a spectator area.

Video Clip:

Accident Analyses

- What was the likely problem here and how might it have been avoided?

Accident Analyses

- (16) An example of the problem during a preloaded display.

Video Clip:

Accident Analyses

- What was the likely problem here and how might it have been avoided?

Accident Analyses

- In our experience, having investigated nearly 300 fireworks accidents, approximately 70% of crew injuries would not have occurred if the fireworks had been preloaded into mortars.

Accident Analyses

- Electrical firing has the potential to eliminate almost 100% of crew injuries during a display.
  - Unfortunately, accidents caused by the careless use of electric matches produces about the same number of injuries before and after a display than were eliminated during the display.

Accident Analyses

- **Preloading fireworks into mortars and the use of electrical firing has almost no effect on the number and sevarity of spectator injuries.**
- **A recent study found that people are 3 to 5 times more likely to be killed or seriously injured driving to view a display than they are to be killed or seriously injured by the fireworks in the display.**

Accident Analyses

- **The way to avoid spectator and crew injuries is to think about what might go wrong and find easy and effective ways to greatly reduce the hazards!**
- **Experience has shown that this is possible, but you need to know what might go wrong and then you need to think and act to reduce the hazards!**

End of Unit