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# Dud Shell Risk Assessment: Mortar Placement

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The previous article on this topic[1] discussed the general process by which one performs a risk assessment and then applied it to two fireworks display scenarios. One scenario had mortars of the same size together in groups, with each group located at their pre-1990 minimum National Fire Protection Association (NFPA) separation distances. (See Figure 2 of the previous article if needed.) The second scenario had the same mortar groupings, but this time, each group of mortars was located at their post-1990 NFPA distances.[2] The estimated relative cumulative risks for the two scenarios were 550 and 40, respectively. Accordingly, for these scenarios, the new NFPA separation distances should produce more than a 90% reduction in the risk of dud shells falling into spectator areas.

In the current article, hopefully further insight will be gained by considering a few additional scenarios. To keep from unnecessarily complicating the discussion, each scenario in this article will continue with the same basic assumptions made in the previous article. Each scenario has the same show design (the same number and sizes of shells), has the spectators in small areas immediately adjacent to the display site, and uses the same shell drift data[3] and dud shell hazard scale. Thus the relative risk estimates produced in this article will be consistent with the ones from the previous article.

Recall that the relative risk from firing any single shell is the product of the hazard value times the relative probability of occurrence. To calculate the risk from firing some number of the same size shells, multiply the risk for a single shell firing times the number of shells of that size. Then the cumulative risk for the display is the sum of individual risks from firing each size shells. (For a more complete discussion, see the previous article.[1])

### Mortar Placement

Scenario three is more typical of the mortar placements actually used in displays. In this case all the mortars, including finales, are located at the minimum distance required for the largest shell in the display. The risk assessment result for this scenario is 4.8, and the data for this estimate is presented in Table 1.

At a 1998 NFPA Technical Committee on Pyrotechnics meeting, consideration was given to a proposal from a non-committee member that the minimum separation distances be increased from 70 feet per shell inch to 100 feet per shell inch. The committee tentatively decided not to make the change; however, it might

**Table 1. Dud Shell Risk Assessments for Three New Mortar Location Scenarios.**

| Shell Size (in.) | Quantity in Body / Finale | Hazard Scale | Scenario 3 | | Scenario 4 | | Scenario 5 | |
|---|---|---|---|---|---|---|---|---|
| | | | Probability | Risk | Probability | Risk | Probability | Risk |
| 3 | 130 / 100 | 1 | 0.000 | 0.0 | 0.005 | 1.2 | 0.000 | 0.0 |
| 4 | 65 / 0 | 2 | 0.000 | 0.0 | 0.005 | 0.7 | 0.000 | 0.0 |
| 5 | 30 / 0 | 3 | 0.000 | 0.0 | 0.005 | 0.4 | 0.000 | 0.0 |
| 6 | 15 / 6 | 5 | 0.001 | 0.1 | 0.005 | 0.5 | 0.000 | 0.0 |
| 8 | 8 / 0 | 9 | 0.004 | 0.3 | 0.005 | 0.4 | 0.000 | 0.0 |
| 10 | 4 / 0 | 13 | 0.025 | 1.3 | 0.005 | 0.3 | 0.001 | 0.1 |
| 12 | 2 / 1 | 17 | 0.060 | 3.1 | 0.005 | 0.3 | 0.005 | 0.3 |
| | | | Cum. Risk | 4.8 | Cum. Risk | 3.8 | Cum. Risk | 0.4 |

be instructive to consider what effect using the greater distance would have on the spectator hazard from dud shells. To do this, the cumulative risks for two additional scenarios are estimated. In one case, scenario four, it is again assumed that there are separate groups for each size mortar each of which are positioned at the 100 feet per shell inch distance for that shell size (similar to scenarios one and two). In the other case, scenario five, it is assumed that all mortars, regardless of size, are positioned together at the minimum distance for the largest size shell (similar to scenario three). The cumulative risks for these two additional scenarios are 3.8 and 0.4, respectively, and the data for these are also given in Table 1.

The results for the three new scenarios, compared with two scenarios from the previous article, are discussed below, following presentation of a scenario involving angled mortars.

**Mortar Angling**

Mortar angling has obvious safety ramifications for the crew performing manually fired displays. This is mostly because dangerous debris from flowerpots and dud shells are propelled slightly away from the crew and unused fireworks. However, the safety ramifications for spectators are less obvious. To examine this, consider the following display scenario. In this case, assume all the mortars are in one large group at the minimum distance for the largest shell size for angled mortars. This corresponds to an offset of 1/3 the NFPA distance toward the main spectator area, with the mortars angled so that the expected point of fall of dud shells is

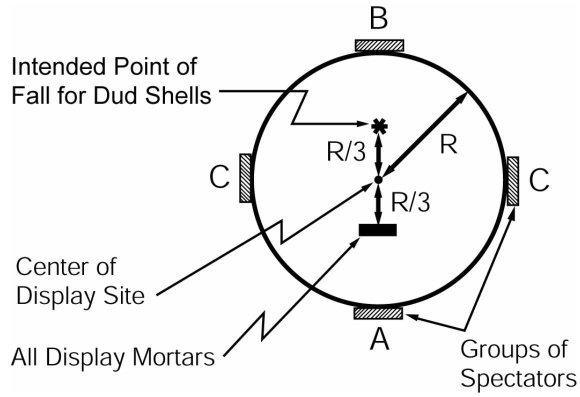


*Figure 1. Illustration of scenario six for angled mortars.*

1/3 the distance past the center of the display site. This setup is illustrated in Figure 1. For the purpose of simplicity in estimating the relative risk from dud shells, it is assumed there are potentially four small groups of spectators. One group **(A)** is just the same as in each of the previous scenarios. Another group **(B)** is immediately adjacent to the display site in the direction toward which the mortars are angled. The last two groups (both designated as **C**) are immediately adjacent to the sides of the display site. Because the distance from the expected point of fall of dud shells is different for each group, their relative risks are also different. The results for each group are presented in Table 2.

The cumulative risk for the collection of spectators in the four groups depends on the number of people in each group. If there are only spectators in group A, such as might be the case for a display fired from the end of a long

**Table 2. Dud Shell Risk Assessments for Angled Mortars, Scenario Six.**

| Shell Size (in.) | Quantity in Body / Finale | Severity Scale | Spectator Area A | | Spectator Area B | | Spectator Area C | |
|---|---|---|---|---|---|---|---|---|
| | | | Probability | Risk | Probability | Risk | Probability | Risk |
| 3 | 130 / 100 | 1 | 0.000 | 0.0 | 0.000 | 0.0 | 0.000 | 0.0 |
| 4 | 65 / 0 | 2 | 0.000 | 0.0 | 0.000 | 0.0 | 0.000 | 0.0 |
| 5 | 30 / 0 | 3 | 0.000 | 0.0 | 0.002 | 0.2 | 0.000 | 0.0 |
| 6 | 15 / 6 | 5 | 0.000 | 0.0 | 0.010 | 1.1 | 0.000 | 0.0 |
| 8 | 8 / 0 | 9 | 0.000 | 0.0 | 0.060 | 4.3 | 0.002 | 0.1 |
| 10 | 4 / 0 | 13 | 0.001 | 0.1 | 0.14 | 7.3 | 0.020 | 1.0 |
| 12 | 2 / 1 | 17 | 0.010 | 0.5 | 0.20 | 10.2 | 0.050 | 2.6 |
| | | | Cum. Risk | 0.6 | Cum. Risk | 23.1 | Cum. Risk | 3.7 |

**Table 3. Summary of Relative Hazard Estimates for the Various Display Scenarios.**

| Scen. No. | Sep. Distance | Mortar Placement Information | Cum. Risk |
|---|---|---|---|
| 1 | Pre-1990 | Vertical mortars in separate groups by size, each at their minimum distance. | 550 |
| 2 | 70 ft/in. | Vertical mortars in separate groups by size, each at their minimum distance. | 40 |
| 3 | 70 ft/in. | Vertical mortars all in one group, at the minimum distance for the largest shell. | 4.8 |
| 4 | 100 ft/in. | Vertical mortars in separate groups by size, each at their minimum distance. | 3.8 |
| 5 | 100 ft/in. | Vertical mortars all in one group, at the minimum distance for the largest shell. | 0.4 |
| 6A | 70 ft/in. | Angled mortars all in one group, at the minimum distance for the largest shell, and spectators only in an area behind the mortars. | 0.6 |
| 6AC | 70 ft/in. | Angled mortars all in one group, at the minimum distance for the largest shell, and spectators in areas behind the mortars and on the sides of the display site. | 2.7 |
| 6ABC | 70 ft/in. | Angled mortars all in one group, at the minimum distance for the largest shell, and spectators on all four sides of the display site. | 7.8 |

pier, then the cumulative risk is 0.6. If approximately the same number of people are distributed evenly between groups A and C, roughly what might be the case for a display fired from a beach, then the cumulative risk would be the average for those three groups or about 2.7 [1/3 × (0.6 + 3.7 + 3.7)]. If approximately the same number of people are distributed evenly between the four areas, the relative hazard for spectators is the average for each of the groups, or 7.8 [1/4 × (0.6 + 3.7 + 3.7 + 23.1)]. These results are discussed further in the next section.

## Discussion

Table 3 was prepared to facilitate the interpretation of the results for the various scenarios of this and the previous article. The previous article considered scenarios one and two, with groups of the same-sized mortars each placed vertically at the minimum NFPA spectator separation distances for that size mortar. It was found that scenario two, using the post-1990 distances (70 feet per shell inch), when compared to scenario one, using the pre-1990 distances, resulted in more than a ten-fold reduction in the cumulative hazard from dud shells falling into spectator areas. Specifically, the risk value of 550 was reduced to 40. Further, for these scenarios, it was found that the greatest risk to spectators from dud shells was posed by the smaller rather than larger aerial shells.

In scenario three (from Table 1), again post-1990 spectator separation distances are used. However, this time all of the mortars are assumed to be placed vertically in the same location and at the distance required for the largest size shell. The result is another nearly ten-fold reduction in spectator risk (40 was reduced to 4.8). This demonstrates the important safety advantage of positioning all mortars at the location of the largest mortars. Also in Table 1, note that in this third scenario the small shells no longer present the greatest hazard to spectators. In fact, because of the much greater distance between the small mortars and the spectators, the relative risk from small shells is essentially zero.

This article only considered hazards from dud shells falling into spectator areas. However, similar cumulative risk reductions for other potential safety problems are accomplished when all mortars are at the location required for the largest mortars. These safety problems include, debris from mortar explosions reaching spectators, shells being propelled directly into spectator areas from repositioned mortars, etc.

In addition to the spectator safety advantage of locating all mortars together, at the distance required for the largest size shells, there are operational and potential esthetic advantages as well. For manually fired shows, having firing take place in several different places on the site could require several different firing crews. Further it would be more difficult to artistically coordinate the firing from these various crews. For electrically fired displays, firing from several locations will probably require more and longer cable runs. It would also eliminate the possibility of using sand-boxes with various sized mortars intermixed in the same order as the firing cues for the show. Finally, firing each size shell at the minimum NFPA distances results in all shells bursting at approximately the same height in the sky as viewed by spectators near the display site.[4] This tends to result in shells overlapping their bursts in an unattractive jumble of color and allows the use of a relatively small portion of the sky.

In scenarios four and five, using spectator separation distances of 100 feet per shell inch, it was found that the relative dud shell risks were 3.8 for mortars in separate groups each at their minimum distance, and 0.4 when all mortars are located in one group at the distance required for the largest size. These are each about a ten-fold reduction in risk compared with the same mortar groupings using 70 feet per shell inch. Specifically the cumulative risks drop from 40 to 3.8 and from 4.8 to 0.4 for scenarios two and three when compared to scenarios four and five, respectively. This is a significant risk reduction; however, an important question is whether this further reduction is needed. Is the problem of dud shells falling into spectator areas sufficiently large that additional measures need to be taken? This is not a technical question, and there is not technical answer for it. However, note that the relative risk for 100 feet per shell inch separations with groups of mortars each a the minimum distance (risk value 3.8, scenario four), is about the same as that from 70 feet per shell inch separations with all the mortars at the distance for the largest shell (4.8, scenario three). Accordingly, if some hazard reduction was desired, without having to increase the overall separation distances, the NFPA code could be revised to require that all mortars be placed at or near the distance required for the largest size. Most operators already do this, and these operators must already have the least problem with dud shells potentially falling into spectator areas.

As a final set of scenarios (six-A, six-AC, and six-ABC), the situation of angled mortars was considered. In each case, angling mortars will be safer for a manual firing crew for the reasons discussed above. However, in terms of relative spectator risks from dud shells, the safety ramifications of mortar angling depend on the distribution of people around the display site. When spectators are located all around the site in approximately equal numbers (scenario six-ABC), it is more dangerous for the spectators than is vertical mortar placement (risk value 7.8 versus 4.8 for scenario three). Thus, it can be concluded that when spectators surround a display site in approximately equal numbers, the mortars should generally be angled no more than the minimum needed for crew safety.

When spectators are approximately evenly distributed around half of the display site, behind and to the sides of the mortars (scenario six-AC), the relative risk drops to 2.7 which is lower than for vertical mortars (4.8 for scenario three). In this case mortar angling improves safety for both crew and spectators. When spectators are located only in the area behind the mortars (scenario six-A), then there is an even more significant reduction in risk, to only 0.6. (Note that this is about the same reduction in risk as for scenario five with its separation distance of 100 feet per shell inch.)

**Conclusion**

In some ways this and the previous[1] article simply stated the obvious (i.e., duds are less likely to fall into spectator areas if the distance to spectators is greater). Also these articles made a number of simplifying assumptions (e.g., all spectators are in small areas immediately adjacent to the display site boundary). However, hopefully the information on the magnitude of the effect of various setups and distances on safety is useful, even if the estimates are based on simplistic scenarios.

There are few if any easy answers in risk management and the hard part is not coming up with relative risk estimates. The hard part is trying to decide when something is safe (i.e., when have the risks associated with an activity been reduced to an acceptable level). Accordingly, the purpose of these articles was not to provide the answers, but rather to provide information to aid display companies in finding their own answers.

**References**


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