Fireworks Shells Subjected To a Modified Height-To-Detonation Test

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ABSTRACT

Initiation of fireworks articles, as by a fire, can result in communication to adjacent articles and at times transition to a mass explosion. Such an event can be catastrophic. In a quest to discover the process by which this transition occurs and thereby work to mitigate it so as to prevent the dire consequences, a series of research programs was established.

This paper reports the findings of attempts to cause communication within a linear array of fireworks shells confined in steel pipes and to measure the shell-to-shell communication rate. The array of shells was initiated with an explosive booster charge.

The findings indicate that such an array, with the given confinement and initiation stimulus, is not conducive to the sympathetic initiation of the tested fireworks shells.

Keywords: height-to-detonation, HtD, fireworks aerial shell, VoD probe, rate of propagation, RoP, explosion test

Introduction

The challenge that confronts the fireworks industry is the determination of the initiation-to-explosion transition mechanism of piles (stores) of fireworks so that methods to mitigate this transition can be developed and applied to prevent the potentially catastrophic consequences in processing, storage, and transport of fireworks. Once mitigation methods have been devised, their effectiveness can only be assured through solidly-based quality assurance processes for the fireworks shells.

In an earlier publication,[1] it was indicated that it would be possible to establish "safe" process and storage "heights" for energetic materials using the Height-to-Detonation (HtD) test. Simply stated, the HtD[2–5] test is performed to determine the potential for an explosion by taking "core" samples from a pile of energetic material. Such a hypothetical pile is shown in Figure 1, where similar diameter pipes (2, 3, 4, and 5), a heavy-walled pipe (1) and a large-diameter pipe (6) are located within the pile to indicate heights relevant to the HtD test. It is seen that as a "core" of energetic material is taken from the edge to the center of the pile, the "core" height increases.

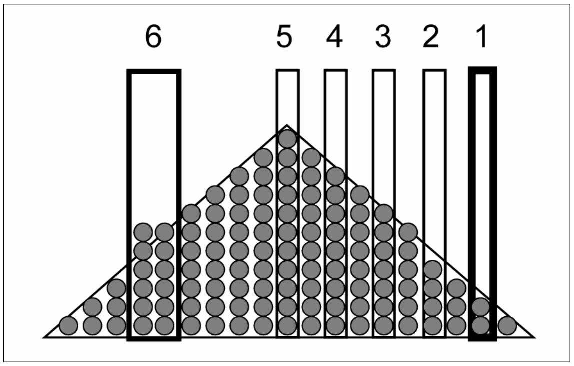

Figure 1. Pile of fireworks simulation.

The HtD test is performed by first establishing the pipe configuration (pipe diameter, wall thickness, and practical length) required for confinement to cause an explosion or detonation and the type of initiation system relevant to the perceived ignition hazards. The ignition source can be an electric match, squib, detonator, pyrotechnic composition, booster, or any other thermal source including a fire external to the pipe. Typically the pipe is configured with a closed bottom and open top. Next, an amount of energetic material is placed in the pipe and ignited. If no explosion occurs, the amount (height) of material is increased. The procedure is repeated until an explosion occurs. If no explosion occurs, the tests are performed in a larger diameter pipe and the test procedure is again repeated until an explosion occurs. Additional tests can then be performed to confirm this critical height. Ideally, this critical height value must then be observed in all manipulations, storage and transport situations.

Test Program

As indicated, variations of the HtD test can be used to determine safe processing, as well as, storage and transport stacking heights of energetic materials. In the specific case of determining the critical height for fireworks shells, the HtD test was modified to:

1) Obtain reasonable primary confinement
2) Make use of various sizes of shells
3) Allow the use of different ignition systems
4) Facilitate loading

Primary confinement is defined as that "felt" immediately by the reacting energetic material. For example, on ignition, a lift charge of a well-seated fireworks shell in a mortar, "immediately feels" the confinement from the mortar tube and the inertia of the shell. The pressure profile from such a scenario would have a short rise-time. On the other hand, if a fireworks shell is "held-up" half way in the mortar so that a substantial volume is available for the lift charge gases to expand into, then the pressure profile would have a long rise-time and the shell would not experience the "immediate feel". A more extreme situation would be the lift charge of a single shell functioning, for example, in an empty cargo container.

To achieve the desired level of primary confinement, fireworks shells were loaded in steel pipes sized as those used for fireworks mortars. Nominal 3-, 4- and 5-inch Schedule 40 pipe was used. Such pipe sizes not only facilitated the loading but also allowed the shells to be packaged so that loading would be safer. The 3-m length of each pipe was painted in four colours, each section being 75-cm long, so that if they fragmented, the source of the fragments could be identified. A steel angle was aligned with the pipe to be loaded, both of which were resting approximately 1.5 m above the ground on wooden trestles. The shells were placed end-to-end (Figure 2) on a strip of single-sided, corrugated cardboard on the steel angle (Figure 3). The cardboard was then wrapped around the shells and held in place with adhesive tape. The width of the cardboard was shorter than the perimeter of the shells, such that when wrapped around the shells, it left a gap in which a velocity of detonation (VoD) probe was secured with adhesive tape.

Figure 2. Shells assembled end-to-end (Trial 1).

Figure 3. Shells on cardboard on steel angle (Trial 1).

The VoD probe is basically a co-axial cable, visible in Figures 2 and 3, with the central conductor being a resistive element. Detonation of an explosive results not only in very high pres-

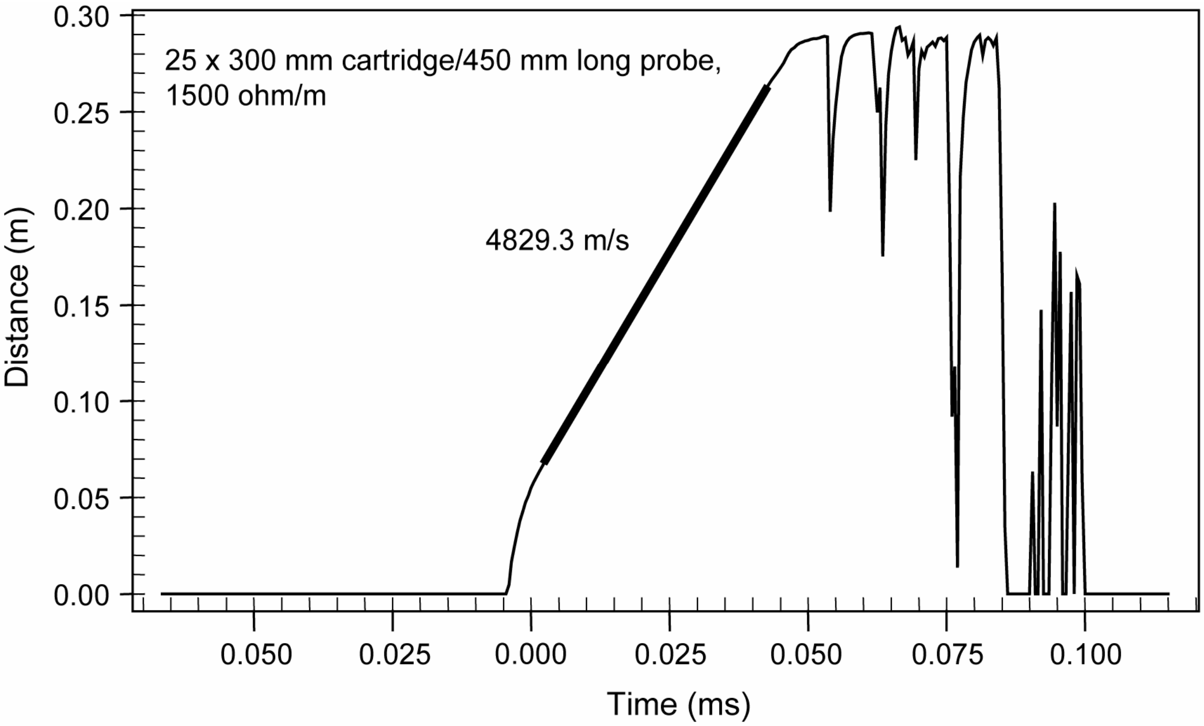

Figure 4. Typical VoD probe trace for a commercial explosive.

sures in the reaction zone but also ionization of the reaction products and materials (air) in the immediate vicinity. Therefore, when such a probe is used in conjunction with an explosive, the detonation causes a collapse of the cable and possibly ionization, which results in the electrical shorting of the cable metallic shield to the inner conductor. Connected to a constant current or constant voltage source, the rate of collapse, as obtained from the output of the probe circuit, is proportional to the VoD or in this case the rate of propagation (RoP) of the test material. This terminology has been adopted so as not to imply that the measurement recorded is necessarily a detonation. The data were recorded with the use of a DataTrap,[6] an instrument designed to monitor the VoD of explosives in mining applications, such as in bore holes. A typical VoD trace for a commercial explosive is shown in Figure 4 where the steady state value is 4830 m/s. The DataTrap requires a minimum initial value of electrical resistance of the VoD probe. Therefore, in these trials, a length of probe was assembled to extend beyond the booster end of the 3-m long pipes used. As a result, the communication-rate trace does not start at a distance of 0 m but somewhere beyond 2 m. Traces starting at 0 m have been relabeled.

Besides monitoring the communication rate, a monochrome, high-speed video-camera[7] was used to record the event at 500 frames per second. In addition, the number of recovered fragments was noted.

Five trials were performed to measure the communication rate of fireworks shells under such confinement. Display shells, all in the same orientation, were loaded into 3-m long, Schedule 40 steel pipes. Due to concerns of accidental ignition during loading, the quick match leaders were removed from all shells. Once the assembly of shells was wrapped, it was remotely pulled into the pipe with a rope. When in place, a 175-g Pentolite booster was attached against the top (not the lift charge end) of the first shell at one end of the pipe to serve as the initiation stimulus. Such a booster was used with the assumption that a high-energy, high-speed stimulus would be required to initiate the fireworks shell train. The booster was initiated with an electric detonator via a short piece of detonating cord. The opposite end of the pipe from the booster was left open in all the trials.

Trials were conducted with 76-, 102- and 127-mm star shells and with 76-mm report shells. These are indicated in Table 1. A selection of these shells was available for these tests, and an attempt was made to use as many similar shells as possible in the same test to better evaluate their communication behaviour.

If the array of shells were to function, then a reaction record similar to that shown in Figure 5 would be obtained. The shells in the pipe simulate discrete pockets of energetic material, along the center of the pipe, surrounded by inert shell material comprising the shell structural elements. The detonation of the explosive booster would produce a steep slope for a duration equal to its reaction time. Then, if the explosion of the first shell causes initiation of the adjacent shell and it in turn causes initiation of successive shells and if only the explosion of the discrete energetic material pockets produces sufficient pressure to collapse the VoD probe, the staircase record shown in Figure 5 would result. Each inclined step indicates the time to initiation and duration of the reaction of each pocket of energetic material.

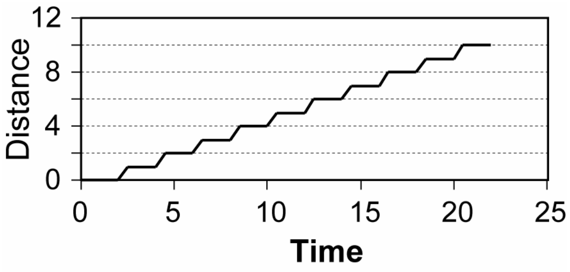

Figure 5. Graphical representation of the sequence of discrete explosions.

Table 1. Description of Shells Used in Each Test.

Trial	Shell Size (mm)	Shell Type	Shell Case	Shell Description	Pipe Length Filled (cm)	
					Incremental	Total
1	76	Star	Paper	14 - blue star	122	305
				14 - purple to green	122	
				7 - blue to glitter	61	
2	76	Star	Paper	14 - white flitter	122	304
				5 - red	44	
				4 - silver	35	
				2 - green	17	
				2 - yellow	17	
				1 - colour change	9	
				7 - spider	60	
3	76	Report	Plastic	25 - report shells	190	190
4	102	Star	Paper	14 - purple Mg	122	200
				4 - white	35	
				3 - red Mg	26	
				2 - blue	17	
5	127	Star	Paper	14 - red, white & blue Mg	190	294
				8 - red & blue Mg	104	

Table 2. High-Speed Video Observations of Trial 1.

Frame	Location		Trial 1 Observations from High-Speed Video (500 Frames/Second)
	B	OE	
13–22	B		Explosive booster detonated. A small bright flash accompanied by black smoke was seen as the booster detonated.
23–28	B		Pipe fragments and possibly those from first shell strike the ground.
29–36	B		Small fireball from the explosion of a second shell is observed.
37–40	B		Fireball from second shell expands to 3 m φ* and is projected from end of pipe.
41–48		OE	Fireball, 2 m φ, appears, accompanied by horizontal projection of at least 2 shells.
49–54	B	OE	Fireballs increase in size by approximately 50%.
55–63	B	OE	Fireballs are the same size and extend from both ends by approximately 6 m.
64–68		OE	A second smaller fireball separates from main. One of ejected shells strikes the ground, 6 m from end of pipe.
69–82	B	OE	Fireballs continue to expand. Pipe seen tilting upward from horizontal at end “B”.
83–86		OE	Smaller fireball extinguishes. Second ejected shells at 10 m from end of pipe (edge of field of view of camera).
87–102	B	OE	Pipe continues to tilt – at approximately 30° from horizontal at end “B”.
103–108	B	OE	Fireball smoky, approximately 6.5 m from end of pipe. Very bright fireball approximately 6 m φ.
109–148	B	OE	Smoky fireball, approximately 12 m from end of pipe Smoky fireball, extends approximately 10 m from end of pipe. Pipe continues to tilt – at approximately 45° from horizontal at end “B”.
149–230	B	OE	Smoke moves away from end of pipe. Smoky fireball continues to evolve, extends approximately 12 m from end of pipe. Pipe continues to tilt – at approximately 90° from horizontal at end “B”.
231–298	B	OE	Smoke moves away from end of pipe. Smoky fireball continues to evolve, approximately 12 m φ. Pipe continues to tilt – at approximately 120° from horizontal at end “B”.
299–399 (End of record)	B	OE	Smoke continues to move away from end of pipe. Smoky fireball continues to evolve, approximately 12 m φ. Smoke trail from a single shell ejected from original location of end of pipe travels a horizontal path while expanding in size. Pipe continues to tilt – at approximately 180° from horizontal at end “B”.

*φ, is the diameter.

Observations and Results

Figures 6 and 7 show the set up for Trial 1. Table 2 lists observations made on the high-speed video record. Such details are available on all video records, but for brevity only those for Trial 1 are given. Under the heading “Location”, the “B” represents the booster or initiated end of the pipe while “OE” designates the opposite end from that which is initiated. Note that observations are made to the closest “frame”.

Figure 6. VoD probe taped to the side of the column of 76-mm star shells.

Figure 7. Assembled pipe on wooden frame (Initiation from right).

Figure 8 shows the fireball at the initiating end of the pipe shortly after the detonation of the booster. Pipe fragments caused by the detonation of the booster struck the ground producing the visible dust clouds. A large fireball at the exit end of the pipe is seen in Figure 9. Note that the angle of rotation of the pipe relates to frames 87–102 in the high-speed video record.

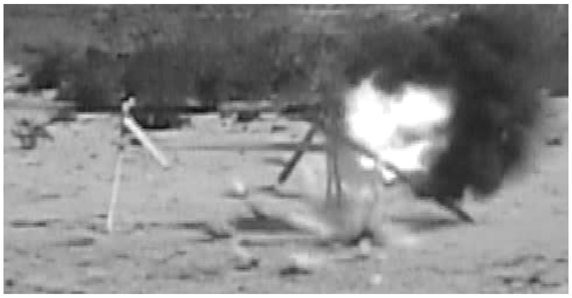

Figure 8. Fireball at initiation.

Figure 9. Fireball at opposite end and rotation of pipe.

Figures 10 and 11 show the damage suffered by the pipe in Trial 1. Detonation of the booster caused the pipe to split and "petal" while at the opposite end a length of approximately 30 cm of pipe was shattered. None of the fragments were recovered. The pipe, thrown a distance of 5 m from the test location, was also slightly bent. Figure 12 shows a schematic of the pipe section indicating the types of shells used and the VoD probe record. The arrows indicate the location on the pipe, of the start of the signal and any other ensuing signals.

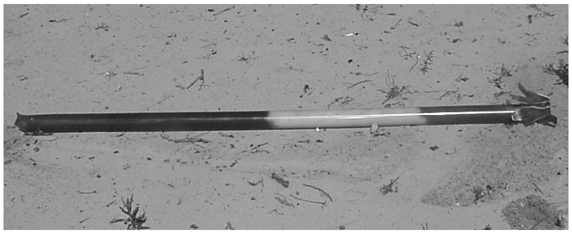

Figure 10. Damage to pipe in Trial 1. Note damage at both ends.

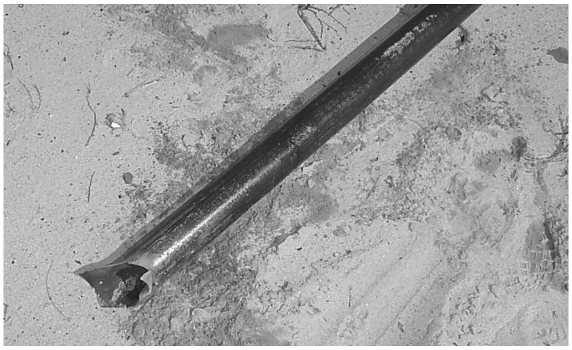

Figure 11. Damage at end of pipe (30-cm length missing).

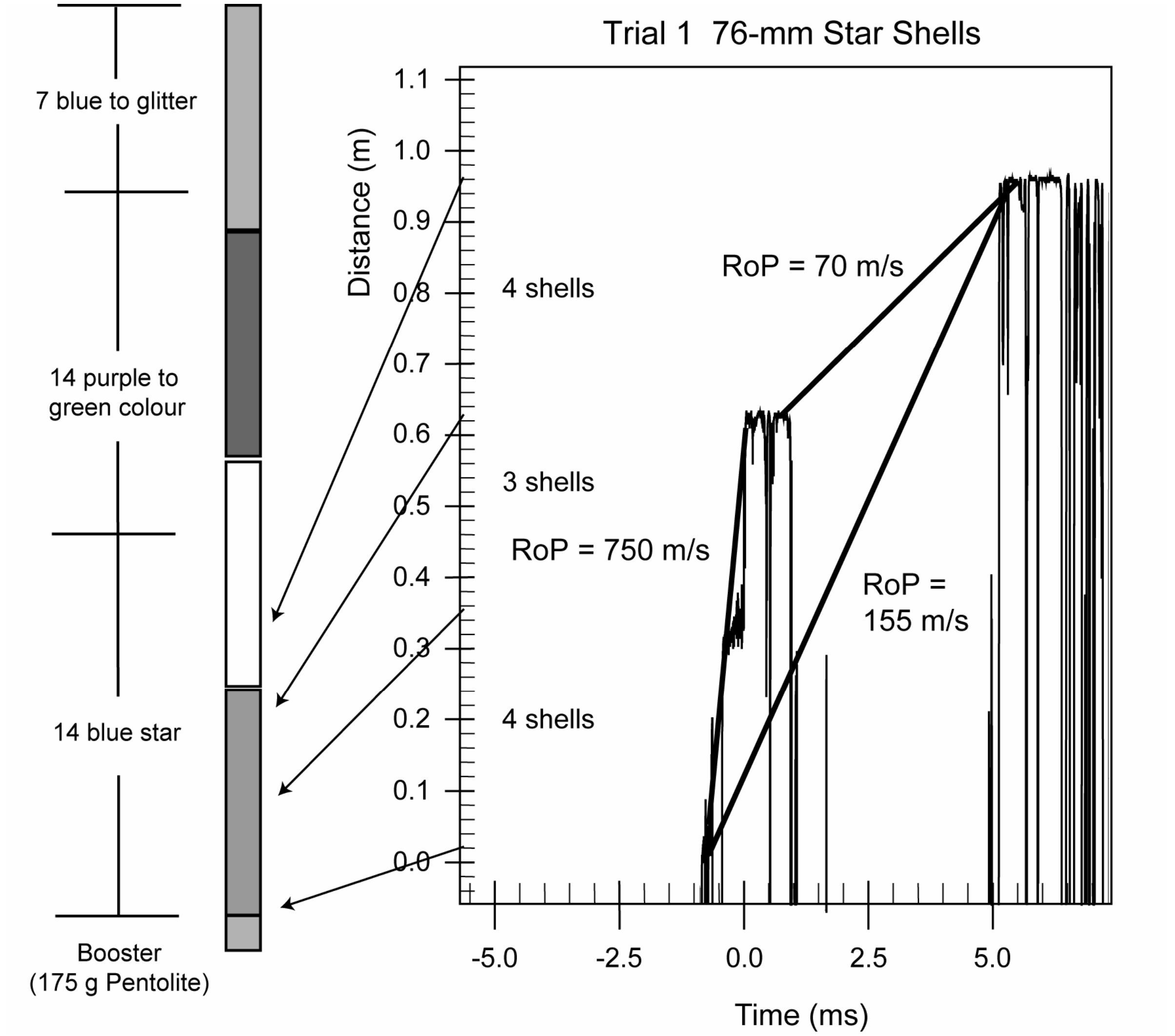

Figure 12. Shell loading scheme and VoD probe trace for Trial 1.

The set up for Trial 2 (Figure 13) was a repeat of Trial 1 with a slightly different selection of the 35 shells. Figure 14 shows the test approximately 60 ms after the initiation of the booster. Note the larger fireball on the initiating end, which indicates that more shells were exploding at the initiating end. However, whatever the initiating mechanism, products of exploding shells were also being expelled from the opposite end. Figure 15, approximately 30 ms later, shows one shell ejecting from the initiated end of the pipe and the trail of three ignited shells propelled from the other end.

Figure 13. Assembly of 76-mm star shells ready to be pulled into pipe.

Figure 14. Photo of Trial 2 shortly after initiation.

Figure 15. Shells being propelled from end of pipe in Trial 2.

Figure 16 shows the location of the pipe after the test. The initiation end of the pipe suffered damage similar to that in Trial 1 while the other end suffered minor damage with a loss of approximately 15 cm of pipe. Figure 17 shows a schematic of the pipe section indicating the types of shells and loading scheme, and the VoD record trace for this trial.

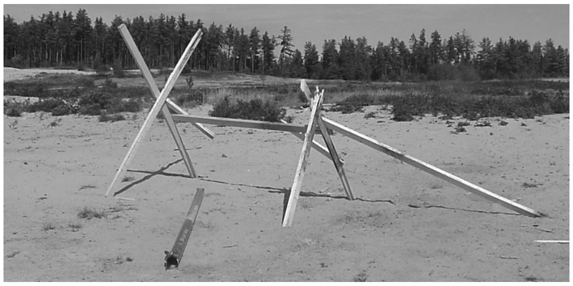

Figure 16. Damage to pipe in Trial 2.

The RoP data collected for shell communication is inconclusive. There is the initial signal from the Pentolite booster charge and the subsequent explosion of possibly up to three shells (white flitter), but then there is no information from the probe on the next 1-m section of pipe. At this location, an event causes the probe to short and then there is no more information. The average RoP within this region, as indicated on the graph in Figure 17, is 70 m/s. The 3-m long pipe remained practically intact with no sign of damage along its length except that already mentioned due to the booster and that at the opposite end caused by several shells exploding as they exited. The high-speed video record indicated similar results to those of Trial 1 except that several shells were ejected from the end of the pipe as already indicated. Several shells exploded at a distance of approximately 100 m from the test location with one shell functioning several minutes after the test. Five intact shells (Spider) were later recovered and showed no evidence of burning or of physical damage.

In Trial 3, a section of the pipe was filled with the same type and construction of 76-mm, plastic-cased, report shells. The shells had no paper wrap, no lift charge and no quick match. A total of 25 report shells were loaded. The shells were placed, in contact and end-to-end with each other as shown in Figures 18a and 18b, occupying approximately 190-cm length of the pipe.

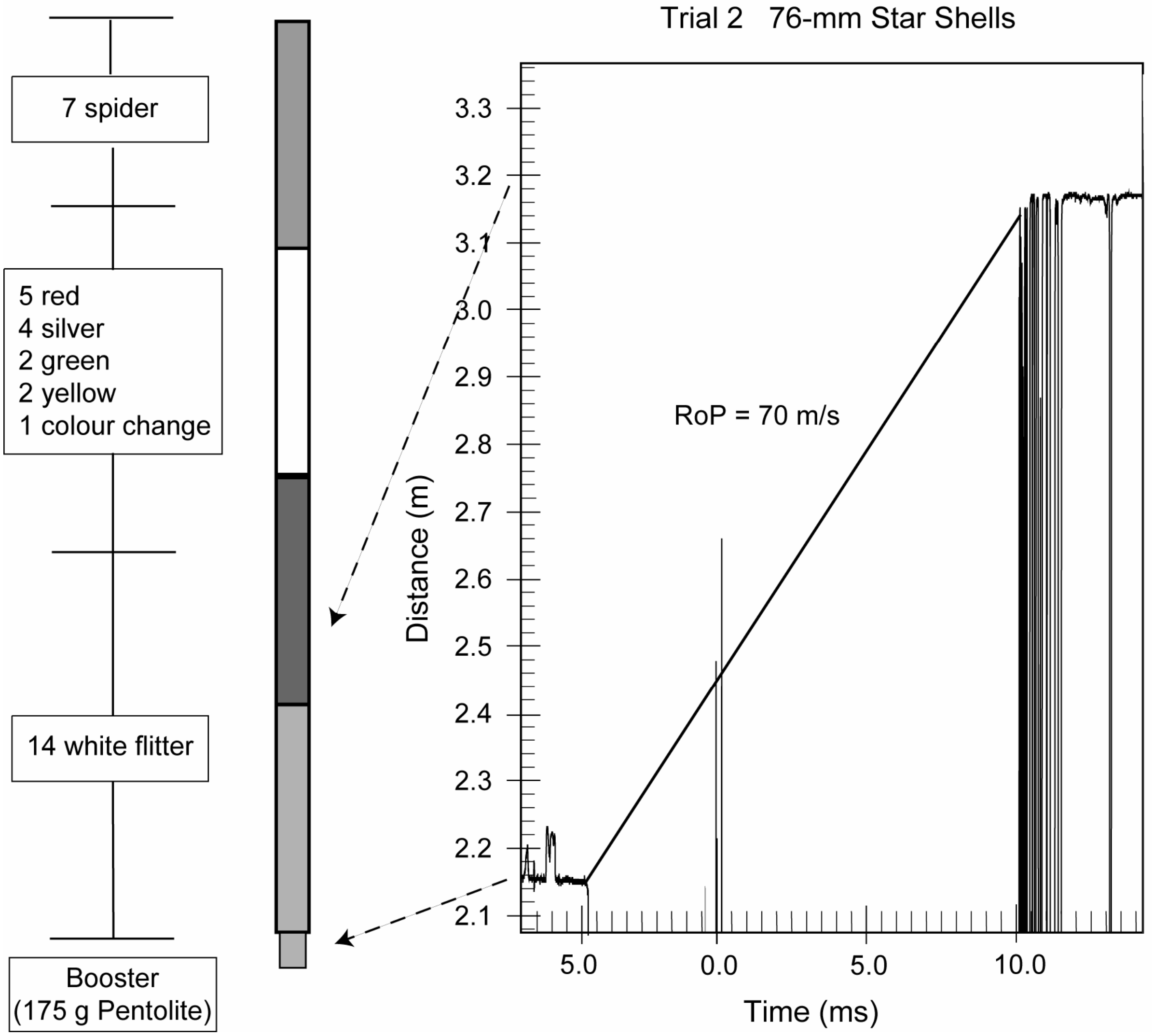

Figure 17. Shell loading scheme and VoD probe trace for Trial 2.

Figures 18a (left) and 18b (right). Plastic cased report shells being prepared for loading in steel pipe.

On initiation of the booster, the VoD equipment failed to trigger. However the high-speed video record indicated a much faster event time than that of Trials 1 and 2. The video shows jetting at both ends of the pipe immediately after the booster detonated. The pipe burst in two (Figure 19) with both pieces being recovered approximately 20 m from the test location. It was noted that it had burst at the point where the column of report shells ended. The booster end of the pipe had fragmented and was deformed over a length of approximately 15 cm. The opposite end remained intact. The damage suffered by this pipe is shown in Figures 20 and 21.

Figure 19. Approximately 300 ms after booster initiation (Note two pipe pieces on left).

Figure 20. Damage due to booster at right end of pipe in Trial 3. Damage towards left end is at location of last shell in pipe.

Figure 21. Damage at location of the last shell of those assembled within pipe (Trial 3).

In Trial 4, a selection of 105-mm cylindrical star shells was loaded into a 4-inch Schedule 40 steel pipe. Figure 22 shows the fireworks assembled in cardboard and ready to be pulled into the pipe at the upper right-end of the photograph.

Figure 22. Trial 4 shells wrapped and ready to be pulled into steel pipe.

Figure 23 shows the violent explosion at the initiated end (right) and the projection of ignited shells from the other end. The pipe can also be seen to be lifting from the support on the left. The explosion caused a piece of pipe to be thrown a distance of approximately 25 m from the test location, as seen in Figure 24. Note that this was the only piece of pipe, in this series of trials, to be quite bent by the explosion. It is possible that this resulted from it colliding with the ground. On closer inspection, it was noticed that the booster had caused the first few shells to explode resulting in splitting and peeling of approximately 30 cm of the initiation end of the pipe. This can be seen in Figure 25. Further, the last metre of pipe, opposite the initiated end, was completely destroyed and in addition, the adjacent 50 cm of pipe showed signs of splitting. This damage can be seen in Figure 26.

Figure 23. Exploding shell products being ejected from both ends of the pipe in Trial 4.

Figure 24. Length of pipe thrown from test location in the background (Trial 4).

Figure 25. Damage resulting from booster and explosion of first few shells (Trial 4).

Figure 26. Detail of damage to non-initiated end of pipe in Trial 4. Note sign of incipient splitting from damaged end to right edge of photograph.

Figure 27 shows a schematic of the pipe section indicating the types of shells used and the VoD probe trace for this trial. There were only sufficient shells to fill a 2-m length of the pipe. The first 120 cm was loaded with 14 "purple Mg" shells while the next 80-cm length was loaded with the selection of shells listed in Figure 27. The VoD probe detected more events over the length of the pipe than in the previous trials. The average speeds indicated in the graph in Figure 27 range from 135 to 155 m/s. As with the other trials, a series of shells was initiated by the booster. Then, at a distance of approximately 200 cm, an explosion was recorded with two others following over the final 1-m length of the pipe. These observations definitely indicate that, except for the few shells at the booster end, the other shells must have moved or were in motion when they were initiated, as they exploded in the final 1-m length of pipe which was originally empty.

In Trial 5, twenty-two, 127-mm cylindrical star shells were loaded into a 5-inch Schedule 40 steel pipe. A selection of 14, red white and blue Mg shells occupied the first 190 cm, while a selection of 8 red Mg and blue shells occupied the next 110 cm. Figure 28 shows the fireworks assembled and wrapped in cardboard, ready to be pulled into the steel pipe. Figure 29 shows a schematic of the pipe section indicating the types of shells used and the VoD probe trace for this trial.

The VoD probe trace indicates shells functioning in the first 0.5 to 1-m length of pipe. Further explosions are then recorded at 2 and 2.4-m. The pipe did not burst but suffered damage at both ends similar to that in Trial 2.

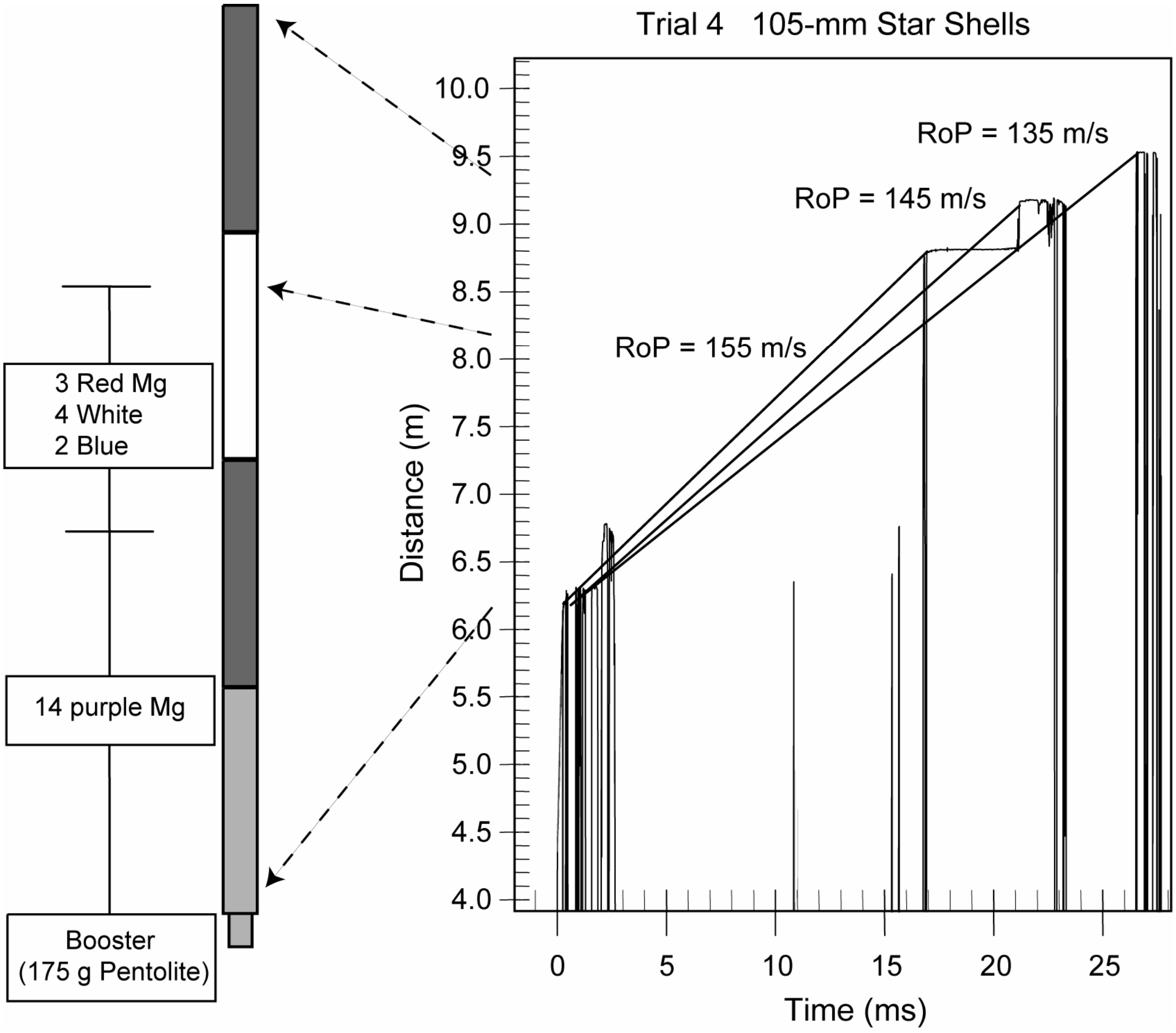

Figure 27. Shell loading scheme and VoD probe trace for Trial 4.

Figure 28. Trial 5 assembly of 127-mm star shells aligned with and ready to be pulled into pipe.

Discussion

The test results assembled from the observations are listed in Table 3. In general, all the pipes suffered minor damage and none of the linear shell assemblies functioned in a steady-state manner. Unfortunately, their somewhat erratic behaviour could not be recorded by the relatively robust continuous VoD probes. The VoD probe traces of Trials 1 and 5 indicate a series of early explosions followed by delayed explosions. The pipes in Trials 1 and 2 suffered damage at their ends probably from one or more shells exploding as they exited the pipes. In addition, explosions can occur along the central area of the pipe as in Trials 3 and 4. Although it could be coincidental, the breaks in

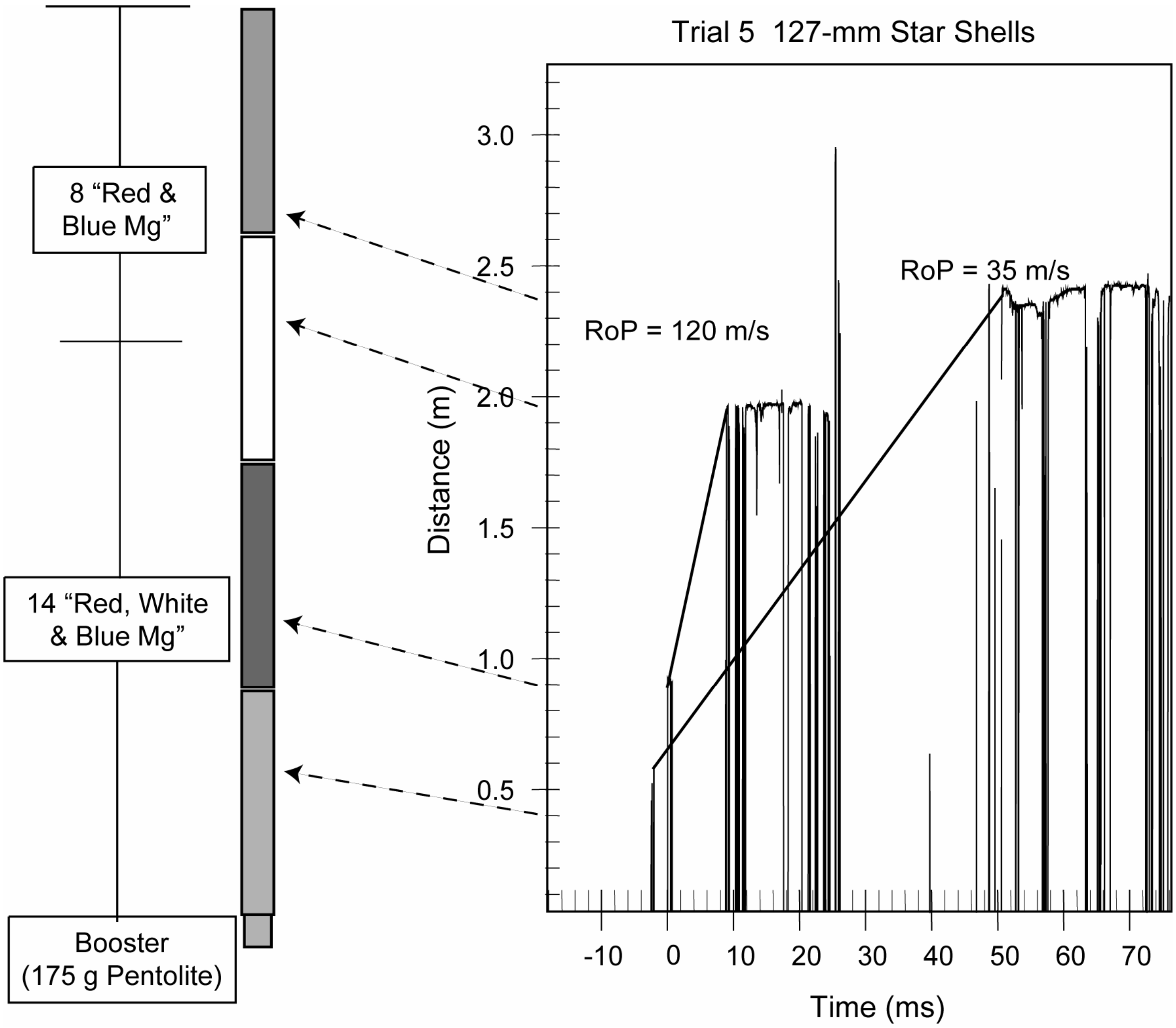

Figure 29. Shell loading scheme and VoD trace for Trial 5.

these pipes occurred at the location of the last shell in the linear assembly. The videos indicate that even after the pipes burst, ignited shells are still being ejected along the path of the original pipe orientation (Figures 19 and 23). The last shell in the assembly exploded, burst the pipe and cleared the path for the ejection of other upstream shells. Possible ignition scenarios are given below.

Some of the very narrow spikes in Figures 17 and 29 could be attributed to temporary "electrical short" condition. That is, the load at that location on the probe was not sufficient to permanently short and/or cut the probe to give a continuous signal.

This series of experiments was approached from the viewpoint that confining a linear array of shells would provide an insight into the initiation mechanism of shells within a large pile. Although there are various examples of catastrophic explosions of stores of fireworks, these tests did not directly provide information as to how initiation of a pile of fireworks can cross over to an explosion.

Initiation Scenarios

Although the VoD probe traces were meant to be interpreted as shells exploding at certain times and at their original locations, it is actually unknown as to which shells and at what location within the pipe they exploded. The high-speed video records indicate that shells were

Table 3. Test Results.

Trial	Shell Size (mm)	Shell Type	Speed Range (m/s)	Minimum Number of Fragments	Pipe Damage		
					Central Region	Initiation End	Opposite End
1	76	Star	70–750	3	Slight bend	Steel torn and curled	30-cm pipe loss
2	76	Star	70	3	No damage	Steel torn and curled	15-cm pipe loss
3	76	Report	N/A	4	Burst	Steel torn and curled	No damage
4	102	Star	135–155	5	Bent and burst	30-cm steel torn and curled	100-cm pipe loss
5	127	Star	35–120	3	No damage	30-cm steel torn and curled	15-cm pipe loss

being ejected from the end of the pipe just milliseconds after initiation of the booster. The question then is, were the shells that exploded in their original location or were they in motion within the pipe when their explosion occurred? The effect of this mass movement of shells was surprising to see on the video.

Multiple shells have been fired successfully from mortars and function at safe heights. However, it had been anticipated that with the close-fitting shells in the pipe as well as its confining effect, fast shell-to-shell rates of propagation would have been observed. The explosion of a shell generates a fireball and burning material, high-speed fragments, and shock and gas pressure. Considering these effects and that the pipe remains intact, the possible means of shell initiation and explosion are as follows.

1) The booster detonates, initiating the first and possibly the second and third shell by brute force (very high blast pressures). The delay element does not play a role in this initiation mechanism. Since the booster was partly outside the pipe, most of its energy is dissipated to the environment outside the pipe, but the pipe will still suffer damage such as fragmentation, deformation, and tearing. Referring to Figure 30, assume, in this scenario, that shells 1 and 2 were initiated.

2) The explosion of these first two shells causes the initiation of Shell 3 and its immediate explosion. The delay element does not play a role in this initiation mechanism. Since it has been assumed that the pipe is not rupturing, the explosion products and pressures can only be relieved along the axis of the pipe. That is, either outward toward the booster end or inward where most of the pipe cross-sectional area is filled by the shell and cardboard wrap. Since the pipe is quite heavy and the cardboard-wrapped column of fireworks can be pushed through the pipe and shells can be pushed through the cardboard wrap, all shell explosions will tend to push the remaining column of fireworks outward. The flow will depend on the ambient pressure conditions on ether side of the exploding shell. It is also possible that the pressure gradients are conducive to forcing explosion products such as flame, hot particulates and gases around Shell 4 (and possibly those beyond) through the voids among the shell, the cardboard wrap and the pipe wall. These explosion products can ei-

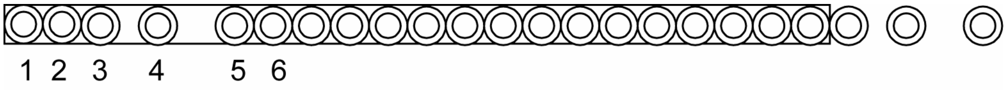

Figure 30. Possible shell initiation scheme.

ther immediately initiate Shell 5 or ignite the delay element and apply sufficient pressure to move the remaining column of shells. This same scenario can be occurring on Shell 6, which may have been already displaced from its original location and is moving down the pipe.

3) This whole scenario can repeat itself causing shell movement, shell separation and delayed shell explosions. One can imagine shell separations that are sufficiently large that an explosion of a shell can cause fast column movement and initiation, through crushing, further down the pipe.
4) This initiation and movement of shells and VoD probe is occurring over a period of a fraction of a second and the various scenarios indicated can be occurring simultaneously. This raises the possibility of explosions occurring in opposite order, that is, a shell further down the pipe can explode before a shell that is closer to the booster end. Note also that a moving shell, which has been initiated, can explode at a location away from its original position. This dictates being cautious in reading the RoP records.
5) The fact that shells are being ejected indicates that there is shell motion and not detonation occurring down the length of the pipe. In fact, shell motion can occur in both directions!

The data indicate that a continuous initiation-to-explosion mechanism is not obvious from these results. It is surprising that if the explosion of a shell cannot sustain the phenomena of initiation of the adjacent shells, in this one-dimensional array, how it is possible for piles of fireworks to transition from the ignition of one shell to a mass explosion! What is the mechanism? Flame propagation in voids among the shells could play a major role. Further research into the subject of shell-to-shell communication mechanisms is currently in the planning stage.

Information on these trials was acquired from high-speed and standard video records and from the damage sustained by the pipes. However, the results indicate that more work is required in the area of detection, that is, investigating the use of more mechanically sensitive VoD probes or using optically sensitive devices to detect time of explosion and track flame propagation. Increasing confinement by physically constraining the shells can also increase the probability of continuous explosions within the pipe. However, if flame front propagation among the shells plays a role in mass explosions of piles of fireworks shells, then the clearance between the shells and the pipe is critical and confining the shells may only be practical by capping the ends of the pipes. This may also require increasing the pipe wall thickness. The effect of critical diameter is somewhat investigated through the use of increasing diameter shells. Larger diameter star shells (more energetic material) did result in more detection points along probe, but this may have been mostly due to the higher concentration of energetic material per unit length. In addition, the critical diameter can be effectively decreased by confinement.

A more fundamental approach to initiation-to-explosion transition is also being considered. It would require the characterization of the fireworks energetic components with regard to thermal, mechanical, and shock sensitivity. Some of this data may be available but may not have been generated from the point of view of explaining communication from one initiated article to proximate articles and thereby resulting in a mass explosion. As originally described, the discrete pockets of energetics surrounded by inert material require an initiation mechanism similar to that of shock initiation of explosives to cause a mass explosion within a short period. Tests must be so designed to investigate and resolve this issue.

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