

EXECUTIVE SUMMARY

ES 1. Summary

The Incident

An explosion occurred during a fireworks display held at a fete at the Holy Spirit Primary School, Sparkes Road, Bray Park at 19:47 hours on Saturday 20 May 2000. Three 2” Roman candles exploded and the steel tubes holding these Roman candles fragmented causing one fatality and resulting in seven people receiving serious injuries. Dominique Maree Baxendell, an 11-year-old grade 7 student at the Holy Spirit Primary School, received fatal injuries. People receiving serious injuries included the following:

- ▼ □ Lorraine Susan Taylor (36 years) received extensive loss of frontal lobe of forehead and brain, loss of one eye, deep laceration on the left side of her face from brow to jaw and other injuries
- ▼ □ Kevin James Crutcher (38 years) received a traumatic amputation of lower right leg
- ▼ □ Benjamin George Plucknett (12 years) received a partial amputation of right foot
- ▼ □ Kimberley Wood (10 years) received deep lacerations to upper thigh adjacent groin area
- ▼ □ Daniel James Morgan (16 years) received minor lacerations to left arm, bruising to chest, and hole in arm from shrapnel;
- ▼ □ Miriam Elizabeth Sullivan (14 years) received a cut to right foot requiring stitching; and
- ▼ □ Graham Stratford (43 years) received perforated right eardrum.

Scope

The Explosives Inspectorate was given directions by the Coroner to conduct an investigation into the explosives incident. This investigation was separate from and in addition to the Police investigation. The scope of the investigation was to determine the nature and cause of the incident and to recommend ways to prevent a similar explosives incident from happening again. In addition, other issues to be addressed included a review of training activities, competency of the fireworks industry, use of metal hardware in connection with fireworks displays, the adequacy of resources for the Explosives Inspectorate and appropriate insurance for fireworks displays. An investigation team was formed to investigate the explosives incident.

Details of the Event

The explosion occurred when the fireworks display had been underway for approximately one minute and fifty seconds. Before the explosion occurred, Mr Stratford had lit the fuse of one 2” 8 shot white tail Roman candle in tube A as shown below and then lit a second 2” 8 shot white tail Roman candle 3.6 metres away. The first comet of the 2” 8 shot white tail Roman candle in tube A functioned normally. Three seconds later the explosion occurred. The explosion was described by a witness as ‘extremely loud and intense and created a powerful shock wave’.

Nature and Cause

The Roman candles in twin tube steel fireworks stands involved in the explosion at the scene are shown below. The three 2” Roman candles in tubes A, B and C exploded. These Roman candles were the two 2” 8 shot white tail Roman candles in the twin tube steel fireworks stand (tubes A and B) and one 2” 5 shot gold tail Roman candle (tube C) in a twin tube steel fireworks stand 900mm away from the other Roman candles. Each firework stand consisted of a base plate with two steel tubes 500mm long, 76mm outside diameter and 3.6mm wall thickness welded to the base plate. The Roman candles were a close fit inside the steel tubes.

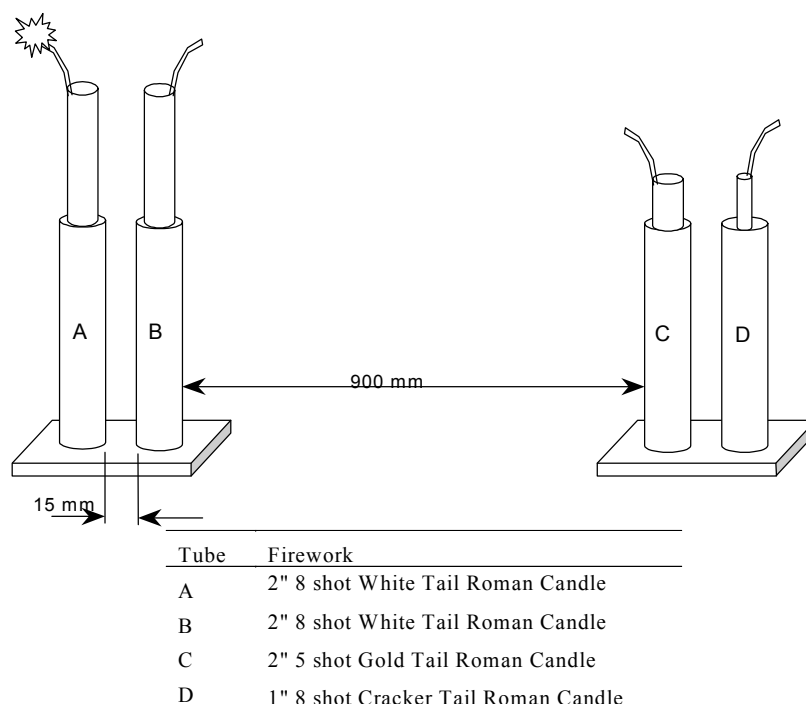


Figure ES 1: Configuration of Roman candle fireworks in twin tube steel fireworks stands

The energy released from the three exploding Roman candles fragmented the three steel tubes in which they were standing. Some of these steel fragments caused serious bodily injury and one fragment from tube B identified as Police Exhibit No: 119 struck Dominique Maree Baxendell. Fragments of various sizes were found at various distances up to approximately 175 meters from the blast centre. Fragments were found in the fireworks display area, spectator-viewing locations on the school oval, outside the barricaded-off safety zone area of the display, and the adjoining neighbourhood. Forty-two pieces of steel fragment were recovered.

The investigation has concluded that, in the operation of the 2" 8 shot white tail Roman candle in tube A, the first comet had functioned normally. A three second delay between the firing of the first and second comets being fired was expected. The second comet was expected to be expelled from the Roman candle when the explosion occurred. This Roman candle exploded due to the comet exploding. The comet exploded within a very short delay after ignition in close proximity to its at rest position in the Roman candle. The exploding comet caused the remaining unburnt comets and black powder in the Roman candle to explode en masse. The cause of the comet exploding was due to a physical feature in the comet, namely the porous and permeable nature of that comet. The porous and permeable nature of the comet allowed the burning rate of the comet, which is normally a controlled rate of burn like a cigarette type burn, to accelerate through the porous and permeable areas leading to an explosion.

The exploding Roman candle caused the surrounding metal tube to expand and fragment, producing high energy steel fragments. The velocity of the steel fragments from tube A has been estimated to be as high as 400 metres per second (1440 km/hr).

Tube A expanded and impinged or struck the adjacent steel tube (tube B) approx. 15mm away containing a second Roman candle, causing the tube to be dented inwards. The dent compressed the contents of the second 2" 8 shot white tail Roman candle, causing that Roman candle to

explode en masse, producing steel fragments similar in form and mass to the first steel tube fragments. The velocity of the steel fragments from tube B was estimated to be as high as 500 metres per second (1800 km/hr). Both steel tubes in the fireworks stand had totally fragmented leaving only the base plate remaining. This 12mm thick steel base plate had been dished about 6mm deep beneath tube A.

A fragment or fragments from the first twin tube steel fireworks stand struck a second twin tube steel fireworks stand 900mm away containing the 2" 5 shot gold tail Roman candle in tube C. The point of fragment impact was approximately 200mm from the top of tube C. The 2" 5 shot gold tail Roman candle also exploded en masse. The explosion caused the tube to partially rupture producing several small fragments and one large fragment, with a steel collar being a part of this large fragment. Tube D was damaged but was not fragmented.

Trials and Investigation

For the investigation under the *Explosives Act 1999*, the investigation included management and evaluation of the evidence (video, testamentary and physical evidence). Interviews were conducted with people connected with the fireworks and the display.

A trial methodology was developed and a trials program was undertaken to establish nature and cause. This included physical and chemical testing of fireworks, components and fragments, field trials, performance tests of fireworks, sensitivity testing, testing fragment behaviour, communication trails, testing features from the life cycle of fireworks, behaviour of comets and non-destructive testing.

Once all information was obtained on the fireworks and evidence, a trials program was developed and undertaken using the information gained from what may occur during the life cycle of the Roman candles to determine why the Roman candles exploded.

The key areas of the trials program included field trials to replicate the explosion observed at the Holy Spirit Primary School oval. Sometimes simulation techniques were used in the trials to replicate the explosion.

A number of methods were developed to make a Roman candle explode from an introduced feature. Once a method was established, Roman candles with this feature were placed into steel firework stands and exploded. The fragmentation was evaluated. The fragments and the effect on the base plate were very similar to that observed from the steel stands at the explosives incident.

Communication trials using a donor acceptor test in a twin tube steel firework stand was undertaken. The donor firework, with the introduced feature to make the Roman candle explode, was placed in tube A of the twin tube steel firework stand. The Roman candle was from a particular batch of white tail Roman candles, which in an unmodified state, would not malfunctioning to explosion. A similar but unmodified Roman candle was also placed in the adjacent tube B of the firework stand. The donor Roman candle in tube A was ignited. The results of these tests showed that the Roman candle in the adjacent tube B would also explode as a result of the Roman candle in tube A exploding. The Roman candle in tube B exploded regardless of the batch of Roman candles used. Again, the fragments and the effect on the base plate were very similar to that observed from the steel stands at the explosives incident.

Trials were then undertaken to evaluate communication of the explosion from the twin tube firework stand holding the two 2" 8 shot white tail Roman candle with the firework stand holding the 2" 5 shot gold tail Roman candle 900mm away. Explosives were used to simulate the impact of metal fragments on the steel tube holding the 2" 5 shot gold tail Roman candle. Trials were undertaken using this simulation technique of impact from metal fragments due to the low probability of hit at a certain location on the tube. The results were similar to that observed from the steel stand containing the 2" 5 shot gold tail Roman candle at the explosives incident. The trial showed that the 2" 5 shot gold tail Roman candle exploded as a result of impact from metal fragments.

Comets from the batch of 2" 8 shot white tail Roman candles that exploded were tested. These comets were found to explode under normal ignition while not contained within the Roman candle. Microscopic examination of the comet showed that there was a porous and permeable feature within the comet that could lead to the comet exploding. The features found in these comets were not found in other batches of Roman candles examined. Trials simulating this feature showed that comets from batches of Roman candles, which did not exhibit explosive behaviour, exploded on ignition in unconfined conditions.

The trials program was successful in determining the nature and cause of the explosion of three Roman candles at the Holy Spirit Primary School on 20 May, 2000 and the subsequent fragmentation of the steel tubes holding those Roman candles.

The metallurgical study by Dr Yeomans found that the failure of the three tubes as a result of the explosion occurred by a process of ductile fracture accompanied by a high level of absorbed energy and gross plastic deformation. It is also Dr Yeomans' view that the method and quality of fabrication of the fireworks stands did not contribute to this failure. The tubes burst and failed as a result of mechanical overload as a direct consequence of the explosion. Dr Yeomans also conducted a study on the fragments of the steel tubes from the trials program and concluded that "the fireworks stands manufactured for the Department of Natural Resources and Mines' trials program are a fair representation, if not and almost exact facsimile, of the fireworks stands in use at the time of the fireworks incident at the Holy Spirit Primary School, Bray Park". Accordingly it can be taken that their behavior in the trials program is an accurate representation of the failure mechanisms that operated in the original fireworks stands used at Bray Park.

People connected with the fireworks display or the fireworks themselves were interviewed as a part of the investigation process. The continuity of the fireworks lifecycle was followed and no known abnormal events were established to have occurred with the fireworks prior to the display. Other users of this batch of 2" 8 shot white tail Roman candles were contacted and three operators reported malfunctions with the 2" 8 shot white tail Roman candles used before 20 May, 2000.

Inspectorate Involvement

Inspector Jim Fowler, Inspector of Explosives, Southern Region was on duty at the Holy Spirit Primary School at the time of the explosives incident. Inspector Fowler was present at the request of the Chief Inspector of Explosives, Mr Robert Sheridan following information provided by Mr Robert Stevenson of ACE Fireworks to the Explosives Inspectorate about Mr Stratford. Inspector Fowler had carried out inspections on the set-ups of both the ACE Fireworks and the Stratford fireworks displays. Inspector Fowler stopped Mr Stratford from setting up and using the aerial fireworks he had prepared for use at the display, as indicated on his set-up plan and "Firing Orders". Mr Stratford was licensed to use ground display fireworks

only and not aerial fireworks. Inspector Fowler had secured but not formally seized the fireworks for which Mr Stratford was not licensed. Inspector Fowler had planned to take a statement from Mr Stratford and take possession of the aerial fireworks after Mr Stratford's display was completed.

Inspector Fowler's involvement was investigated by Inspector John Howe – Inspector of Mines (Mechanical), Northern Regional Office, Mount Isa. His report to the Chief Inspector of Explosives dated 12 July 2000 found that Inspector Fowler had fulfilled the duties expected from an Inspector of Explosives and had acted in an effective and professional manner in this matter as required by the Chief Inspector of Explosives

Accident History.

The investigation has found in June 2001 that 2" Roman candles have been malfunctioning in the United States of America and Canada. There have been two known explosives incidents at Yeppoon, near Rockhampton, in January 1999 and at Mount Isa in November 1999 where 2" Roman candles exploded. In both these incidents wooden stands and not steel tubes were used to support the Roman candles. Following the investigation of the Yeppoon incident, the Explosives Inspectorate issued a Safety Alert, which was distributed to all Queensland licensed fireworks operators and interstate explosives regulatory agencies. An extensive literature search was conducted on fireworks accidents during the investigation.

The Evidence.

ACME Fireworks and ACE Fireworks supplied the fireworks Mr Stratford planned to use at the display. The 2" Roman candles and the aerial fireworks were supplied by ACME Fireworks. Photographs have been taken and plans and drawings have been produced by the Police and the Department of Natural Resources and Mines Investigation Team regarding the evidence and any matters arising with the investigation.

Studies – Post Blast Analysis

Two post-blast studies have been undertaken, one a post blast study co-ordinated through Unisearch, the business arm of the University of New South Wales through the Australian Defence Force Academy and another study by Dr David Kennedy of Orica Explosives. The theoretical studies closely matched the observed results of fragmentation resulting from the 2" Roman candles exploding at Bray Park and also results obtained from the trials program.

The Unisearch study concluded that the computer modelling, supported by a metallurgy and chemical modelling study and data provided by the client, predicts that a Roman candle has sufficient energy, if it explodes for whatever reason, to rupture a thin walled tube and produce fragments. The model closely matches that observed for the actual event. It was also predicted that the comet contribution to the overall pressure dominates over the black powder lifting charges.

Prevention

The main considerations in determining the preventative measures that might be implemented to prevent a similar outcome from a fireworks display in the future:

- ▼ □the adequacy of current fireworks legislation and codes of practice
- ▼ □the competency of fireworks operators
- ▼ □the compliance of operators with the legislation
- ▼ □the Explosives Inspectorate's performance of its role
- ▼ □the management of fireworks displays
- ▼ □the quality of fireworks, and
- ▼ □the risks associated with a fireworks display.

The review into the preventative measures has identified a number of control measures for the risk management of fireworks displays. A number of recommendations have been made based upon these control measures.

Training and Competencies

A review of the approved training courses and an assessment of the competencies of the fireworks industry through a survey of licensed fireworks operators was undertaken. The quality of training was an issue at the time of the accident and directions were given to include evaluation of training into the investigation. It is considered that the quality of the training courses played no direct role in the explosives incident. However the knowledge and skills of the operators, and the continued maintenance of those knowledge and skills, and the education of event organisers and the public, are considered to be important areas in explosives and fireworks safety.

Market Research

An independent market research study was undertaken to investigate safety standards and issues in relation to the fireworks industry. The market research project was designed to gain an understanding of the culture of the fireworks industry, particularly in relation to safety in the workplace. It was also designed to determine customer and community expectations and awareness of hazards and satisfaction levels regarding services provided by the fireworks industry and the Explosives Inspectorate.

Research activities included two focus groups with fireworks operators, a survey of 120 fireworks operators, a survey of 25 event co-ordinators and a survey of 187 members of the Queensland public. The market research provided valuable information from these groups of people.

ES 2 Key Findings

The key findings from the investigation into the nature and cause of the explosive incident are:

1. There was no evidence found to support the fact that the incident was other than an accident to the extent that it was unforeseen and not intentional.
2. Comets contained in 2" 8 shot white tail Roman candles from the batch used at Bray Park had physical features not observed in other batches of 2" white tail Roman candles.
3. 2" white tail Roman candles with comets of these different physical features have a high propensity to explode when confined or unconfined than other comets not exhibiting this feature.
4. Comets consist of a particularly high energy fireworks composition used in other types of fireworks to create maximum noise output such as salutes and reports.
5. An exploding comet can cause the entire Roman candle to explode.
6. When contained within a close fitting steel tube, an exploding Roman candle can rupture and fragment the tube.
7. The explosion of a Roman candle inside a close fitting steel tube can cause an adjacent Roman candle in a steel tube to explode.
8. The explosion of an adjacent Roman candle also can cause the steel tube holding that Roman candle to rupture and fragment.
9. The trials program conducted at the Helidon Explosives Reserve has effectively simulated the explosive incident at Bray Park.
10. The malfunction in the Roman candle in tube A was not an isolated malfunction but similar malfunctions were observed in other Roman candles from the same batch.
11. Some Roman candles from the same batch as the Roman candles used at Bray Park, when fired did explode.
12. The extant Code of Practice, Australian Standard AS 2187, Part 4 is silent on the placement of Roman candles in steel tubes.
13. The fragment which caused the fatal injury to Dominique Baxendell (Police Exhibit No. 119) was identified to have been from tube B.
14. 2" 8 shot white tail Roman candles were supplied to Mr Stratford and Mr Crutcher by a licensed fireworks seller from a batch that had previously been reported to have a fault.
15. Three 2" 8 shot white tail Roman candles, from the same batch as the 2" 8 shot white tail Roman candles used by Mr Stratford in his display, had malfunctioned in fireworks displays prior to 20 May, 2000.

ES 3 CONCLUSIONS

The conclusions have been derived from the investigation into explosive incident and, in particular, conclusions have been derived from the analysis of the incident and the suggestions for improvement.

The conclusions are:

1. The fireworks incident, which occurred at Bray Park on 20 May, 2000, was an accident.
2. The incident occurred as a result of a faulty Roman candle exploding.
3. The placement of the 2" 8 shot white tail Roman candles in the steel fireworks stand resulted in the fragmentation of the steel tubes of the fireworks stand when the Roman candle exploded. The exploding Roman candle in the steel tube caused two adjacent Roman candles in steel tubes to explode, which also fragmented these steel tubes. The fragmentation of the three steel tubes caused metal fragments to be distributed around the display site for distances up to approximately 155 meters. The velocities of these fragments were estimated to be up to 400 metres per second from tube A and up to 500 meters per second from tube B.
4. The confinement of the Roman candle in the steel tube was a major contributor to the tragic consequences of this incident.
5. The unnecessary confinement of fireworks leads to increases the adverse effects of malfunctioning fireworks, thereby increasing the risk to an unacceptable level.
6. From the investigation carried out on the batch of 2" 8 shot white tail Roman candles, it was evident that the Roman candles could malfunction by exploding.
7. Suppliers of fireworks do not have a recognised and formal quality system in place. Quality management principles are not being applied to contemporary standards, which are being adopted throughout the community elsewhere.
8. A review of the Australian Standard AS2187, Part 4, following this incident has identified a number of deficiencies including ineffective safety distances, unsafe work practices and areas where key issues are not addressed. There are areas where the requirements are implicit rather than explicit. There are areas where there is lack of clarity and ambiguity.
9. The Australian Standard AS2187, Part 4 covers outdoor fireworks displays. There are other types of firework activities that are not covered by Codes of Practice, including Australian Standards in the areas of indoor fireworks displays and special effects activities.
10. The reporting of explosive incidents is to understand what has gone wrong, how it has gone wrong, and how the situation may be corrected in the future. Explosives incidents are not being reported to the Explosives Inspectorate to the extent that they should be reported.
11. The levels of competency of licensed fireworks operators were not at a desired level. It is recognised that there is a broad range of competencies within fireworks operators.
12. There was diversity in the quality of training being offered.
13. There was a lack of appreciation on the part of event organisers and other associated persons of their obligations in relation to fireworks displays.

14. There is a lack of information available to fireworks operators and other persons associated with fireworks displays. This information includes Material Safety Data Sheets, Technical Data Sheets and other safety information. Such information is essential so that these people know the hazards in the performance of the fireworks they are dealing with.
15. It is very difficult to find information about fireworks accidents in the literature and elsewhere. The lack of this information is due to two issues – one, accidents and incidents are not being reported and, two, this information, when reported, is not being collated. It is considered that such collation is essential so that the information can be related back to the fireworks industry for their on-going education and awareness. There is insufficient liaison between the regulatory agencies, the Explosives Inspectorate and the fireworks industry to enable a healthy exchange and information on accidents and incidents, investigations, risk management and quality management issues. A very small percentage of fireworks displays are inspected by Inspectors of Explosives. The study of the Explosive Inspectorate resources and their planned activities shows that a very small percentage of the fireworks displays can be inspected.
16. The Explosives Inspectorate, with its available resources, is not able to carry out its planned inspection schedule in all areas of explosive activities.

ES 4 RECOMMENDATIONS

The recommendations are in pursuit of a professional fireworks industry to ensure that a fireworks display is safe and the public is protected from harm. In arriving at these recommendations, cognisance has been taken of contemporary industry practices from other sectors of the community, and in particular, the industries using dangerous goods and hazardous substances.

The following recommendations are made to:

- (a) Prevent a similar outcome from an explosives incident of the nature of that at Bray Park
- (b) Minimise the consequences of any fireworks incident, and
- (c) Encourage the adoption of contemporary industry practices within the professional fireworks industry

The recommendations are:

1. To prohibit the presence of any metal tube, holder, mortar, or other metal equipment that can confine a firework at any fireworks display site.
2. To prohibit unnecessary confinement of any firework.
3. To include, within the Explosives Legislation, explicit obligations on specific classes of persons, including the supplier and the operator, for the quality of fireworks. Such obligations would include the need for an operating and documented quality system and a prohibition on the use of fireworks unless the fireworks have a current Certificate of Compliance.
4. To include within the Explosives Legislation specific obligations and responsibilities for all classes of persons associated with a fireworks display, including operators, assistants, suppliers, event organisers, property owners and the viewing public.
5. To include within the Explosives Legislation specific obligations on the supplier and the user in relation to the provision of Material Safety Data Sheets, Technical Data Sheets and other safety information.
6. To develop and implement a national standard for the quality and testing of fireworks, and in the interim, to develop and implement a Queensland standard.
7. To revise and upgrade the National Code of Practice (Australian Standard AS2187.4) for outdoor fireworks displays to correct and address identified deficiencies, and in the interim, to develop and implement a Queensland set of requirements.
8. To develop and implement National Codes of Practice for the conduct of indoor fireworks displays and the use of fireworks for special effects purposes.
9. To encourage and enforce the requirement to notify the Explosives Inspectorate of all explosive incidents.
10. To restrict the licensing of fireworks operators to persons who have satisfactorily completed an approved training course and who have gained suitable industry experience.
11. To develop the criteria for an industry training package and to ensure the development of that single training package for fireworks operators. Training courses would then be approved based on their compliance with their package.

12. To ensure a system is in place to up-skill existing licence holders to the standards of the new training package and to maintain these competencies in all licence holders.
13. To establish and implement an on-going education and awareness package for all stakeholders associated with fireworks displays, e.g. event organisers, community.
14. To establish an industry liaison committee and to encourage the development of a representative fireworks industry organisation. The purpose of this committee should include review of legislation and standards, incident review, risk management and quality management issues relevant to the fireworks industry.
15. To develop a technical support network and information sharing mechanism between regulators within Australia and overseas.
16. That the Explosives Inspectorate develops readily accessible information sources, including an explosives incident database, and fosters a national explosives incident database.
17. That the Explosives Inspectorate be appropriately resourced and equipped to carry out its enforcement and monitoring functions, and in particular, an increased level of inspection at fireworks displays and to have the capacity to effectively investigate all reported explosives incidents.

All members of the Investigation Team express their sincere condolences to the victims and the affected families of this tragic incident and trust the outcomes and recommendations of this investigation will help to ensure that fireworks displays are safer in the future.

