Annex I

Hazard to Life Assessment

I1 *UN CLASSIFICATION AND DEFINITIONS*

I1.1 *HAZARD DIVISIONS IN CLASS 1*

Under the UN classification, explosives are assigned to Class 1. Class 1 is divided into six divisions and are also assigned to one of thirteen compatibility groups. The six divisions in Class 1 is given in *Table I1.1a.*

Table I1.1a Divisions under Class 1

Division	Explanation (as given in the UN Recommendations)
1.1	*Substances and articles which have a mass explosion hazard* (a mass explosion is one which affects almost the entire load virtually instantaneously)
1.2	*Substances and articles which have a projection hazard but not a mass explosion hazard*
1.3	*Substances and articles which have a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard.* This division comprises substances and articles which give rise to considerable radiant heat or which burn one after another, producing minor blast or projection effects or both.
1.4	*Substances and articles which present no significant hazard.* This division comprises substances and articles which present only a small hazard in the event of ignition or initiation during transport. The effects are largely confined to the package and no projection of fragments of appreciable size or range is to be expected.
1.5	*Very insensitive substances which have a mass explosion hazard*
1.6	*Extremely insensitive articles which do not have a mass explosion hazard*

Goods of Class 1 are also assigned to one of thirteen compatibility groups (A, B, C, D, E, F, G, H, J, K, L, N and S) which identify the kinds of explosive substances and articles that are deemed to be compatible.

The fireworks proposed to be used at the Theme Park will only be goods of 1.3G (UN No. 0335) and 1.4G (UN No. 0336). The pyrotechnic articles to be used will be 1.4G (UN No. 0431) and Class 1.4S (UN No 0432) only.

In addition, the Theme Park operators will also store loose igniters (UN no. 0454, Division 1.4S) which will be attached to fireworks on site. Some fireworks/pyrotechnics may however, be received on site with igniters fitted.

Since all fireworks/pyrotechnics material to be used by the Theme Park belong to the compatibility group G or S, hazards due to incompatibility of goods during storage, handling or transportation are not relevant.

It is to be noted that the terms fireworks and pyrotechnics are often used interchangeably. Both types fall in the general class of pyrotechnics under the UN classification. The best distinction to draw is that fireworks are predominantly for outdoor use and include all aerial types (e.g. rockets, shells) whereas pyrotechnics are limited to items used in restricted spaces such as on stage - be that indoor or outdoor.

I1.2 *DEFINITIONS*

The definitions for explosive substance, explosive article, pyrotechnic substance, fireworks as given in the UN Recommendations are included in the following paragraphs.

Explosive substance is defined as a solid or liquid substance (or a mixture of substances) which is in itself capable by chemical reaction of producing gas at such a temperature and pressure and at such a speed as to cause damage to the surroundings. Pyrotechnic substances are included even they do not evolve gases. Explosive article is an article containing one or more explosive substances.

Pyrotechnic substance is a substance or a mixture of substances designed to produce an effect by heat, light, sound, gas or smoke or a combination of these as the result of non-detonative self-sustaining exothermic reactions.

The shipping name ***'fireworks'*** is defined in the UN Classification System as pyrotechnic articles designed for entertainment. Fireworks may belong to Hazard Division 1.1G (UN 0333), 1.2G (UN 0334), 1.3G (UN 0335), 1.4G (UN 0336) and 1.4S (UN 0337), however the vast majority of display fireworks fall into Hazard Divisions 1.3G and 1.4G. The fireworks proposed to be used by Disney will only be goods of 1.3G (UN No. 0335) and 1.4G (UN No. 0336).

The shipping name ***'Articles, Pyrotechnics for technical purposes'*** is defined as articles which contain pyrotechnic substances and are used for technical purposes such as heat generation, gas generation, theatrical effects etc. The term excludes fireworks. Articles, Pyrotechnics for technical purposes may also belong to Class 1.1G (UN 0428), 1.2G (UN 0429), 1.3G (UN 0430), 1.4G (UN 0431) and 1.4S (UN 0432), but the vast majority are classified as either 1.4G or 1.4S. The goods used by Disney will be 1.4G (UN No. 0431) and Class 1.4S (UN No 0432) only.

NFPA 1123 also provides a definition for fireworks. ***Fireworks*** are devices designed to produce visible or audible effects for entertainment purposes by combustion, deflagration or detonation. It includes fireworks of Hazard Division 1.3G and 1.4G and also Articles, Pyrotechnic of Hazard Division 1.3G, 1.4G or 1.4S.

NFPA 1126 provides a definition for ***pyrotechnic material*** (Pyrotechnics Special Effects Material). A chemical mixture used in the entertainment industry to produce visible or audible effects by combustion, deflagration or detonation. Such a chemical mixture consists predominantly of solids capable of producing a controlled, self-sustaining, and self-contained exothermic chemical reaction that results in heat, gas, sound, light, or a combination of these effects. The chemical reaction functions without external oxygen.

NFPA 1123 also includes a definition for the terms consumer fireworks and display fireworks. The term ***display fireworks*** includes consumer fireworks and those classified as 1.3G and described as Fireworks UN0335 and those described as Article Pyrotechnic and classed as 1.3G, 1.4G or 1.4S.

Consumer fireworks are normally classed as 1.4G and described as Fireworks UN0336.

Compatibility group G includes "pyrotechnic substance or article containing a pyrotechnic substance or article containing both an explosive substance and an illuminating, incendiary, tear-or smoke-producing substance (other than a water-activated article or one containing white phosphorous, phosphides, a pyrophoric substance, a flammable liquid or gel, or hypergolic liquids)".

Compatibility group S refers to substances or articles that are "so packaged or designed that any hazardous effects arising from accidental functioning are confined within the packaging unless the package has been degraded by fire, in which case all blast or projection effects are limited to the extent that they do not hinder or prohibit fire fighting or other emergency response efforts in the immediate vicinity of the package".

I2.1 TYPES & EFFECTS OF FIREWORKS FOR MID-LEVEL & LOW-LEVEL DISPLAY

A general description of fireworks types and effects for fireworks that are likely to be used for mid-level and low level display is summarised in *Table I2.1a*

Table I2.1a General Description of Fireworks Types and Effects

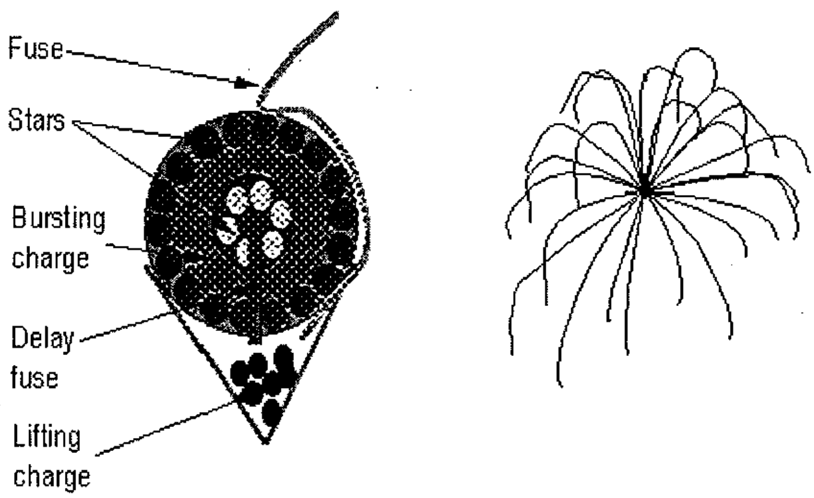
Firework Type	Description	Effect	Approximate burst height
Shell	Spherical or cylindrical unit discharged from a mortar tube by either blackpowder lifting charge or compressed gas	Rises to design burst height (may include visible "tail") at which point fire is transferred (by the delay fuse) to the bursting charge within the shell. This ignites the "stars" in the shell and fragments the shell casing at the same time - leading to spread of stars or effects. An aerial maroon (syn salute) is a specialised type of shell which produces a loud bang (report) instead of a burst of stars. The effect may be enhanced by the addition of metal powder (usually titanium) into the burst of the maroon giving a silver spark in addition to the bang.	75m-100m depending on calibre (3" - 5" shells)
Roman Candle (or Candle)	Tube filled with alternating (but may be only one) payloads and lifting charges. Typical calibres - 14mm to 60mm	The tube ejects comets (stars), bombettes (mini shells) or other effects (eg whistles) in sequence. A typical candle may contain 8 "shots" and have an overall duration of 30-45 seconds	50m-75m depending on calibre and type
Mine	A Unit containing several sub-units, similar in some respects to a shell, loaded into a mortar. The effect however is ejection of the sub-units in a conical pattern from ground-level upwards. Typical calibres 25mm to 125mm	Mines may contain stars, mini-bombettes, effect units (e.g. whistles, serpents etc.) or a combination of these.	30m-60m depending on calibre

Firework Type	Description	Effect	Approximate burst height
Multishot Battery (colloquially "box item" or "cake")	A device comprising multiple firing tubes, each of which may be considered to be a mine or Roman candle. These individual tubes are interconnected to produce firing of extended duration. Typical calibres 9mm - 50mm	These items comprise a combination of the effects as per the individual components.	30m-75m depending on type and calibre.
Comets	Solid composition ejected from a tube as per a Roman candle or shell. Typical calibres 30mm - 50mm	A comet is a long streamer of ascending fire - occasionally (in splitting comet or crossette) fragmenting from an internal charge at the apex of its flight. There is very little debris from such items as they are self-consuming during functioning.	30m-50m depending on calibre.

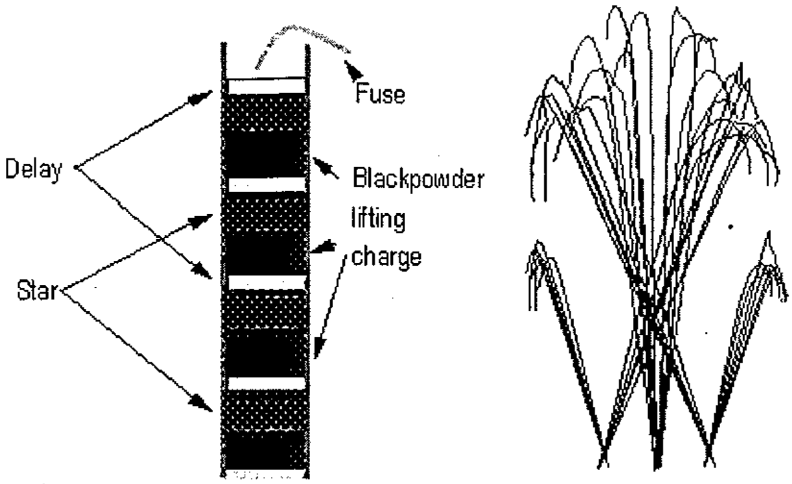
I2.1.1 *Schematic of Fireworks for Mid-level & Low-level Display*

Below are representational diagrams of the various types of firework listed above, and schematics of their effects.

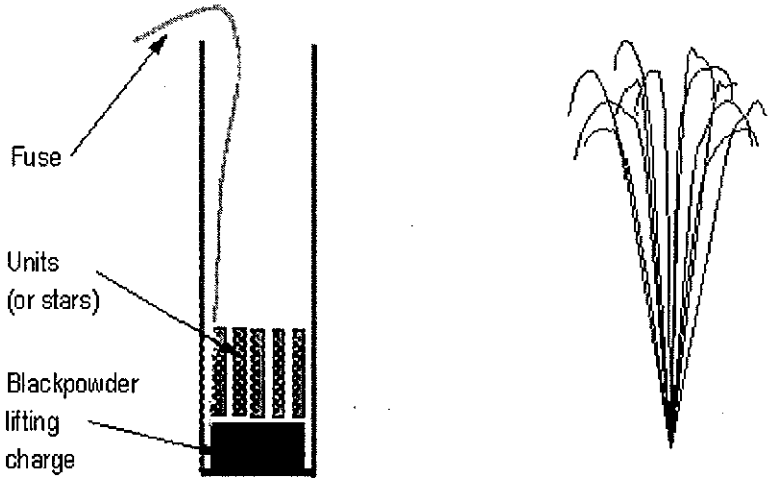
Shells



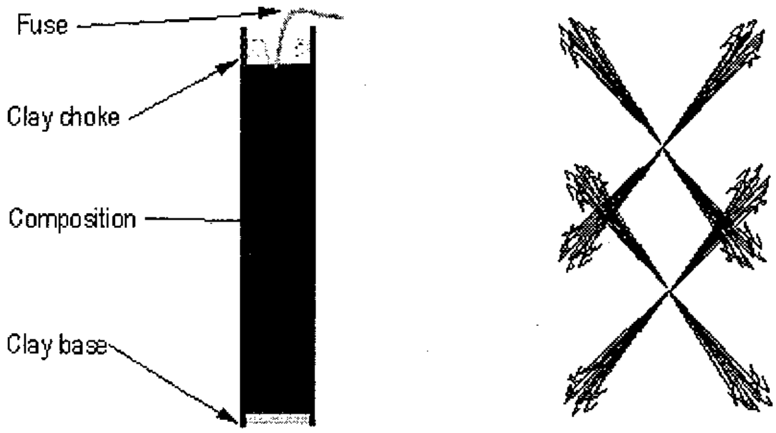
Roman Candles



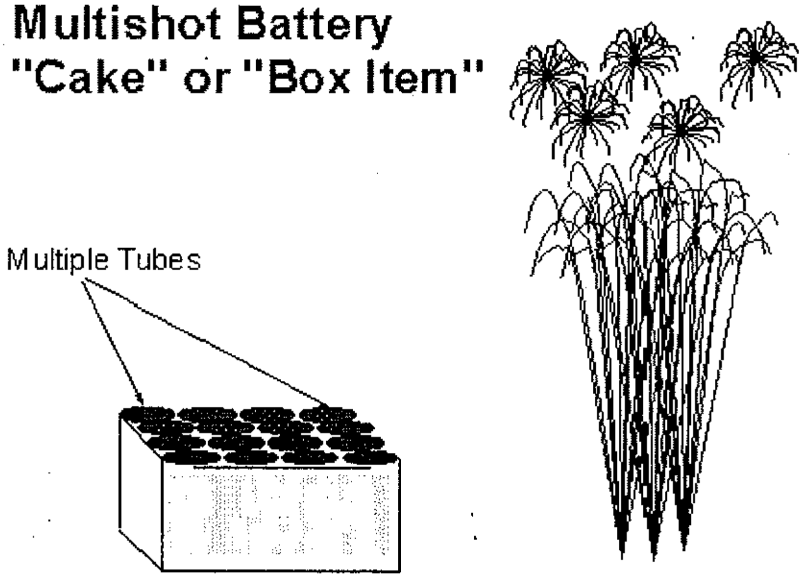
Mines



Gerbs and Fountains



Multishot Battery "Cake" or "Box Item"



I2.2 *TYPES & EFFECTS OF PYROTECHNICS FOR STAGE EVENTS*

A brief description of types and effects of various pyrotechnics used for stage display is given in *Table I2.2a* .

Table I2.2a Types of Pyrotechnics for Stage events

Type	Description	Effect
Stage Maroon	Small pyrotechnic charge containing blackpowder or flash powder contained within relatively strong case. MUST be fired in a suitable "bomb tank" to prevent debris reaching audience	Loud bang
Jet	Tube containing pressed composition	Usually short duration (about 2 seconds) silver or gold shower of sparks
Gerb	Tube containing pressed composition. Typical calibre 19mm - 24mm	Usually long duration (about 25 -45 seconds) shower of sparks. May be Silver, Gold, Gold to Silver, and may contain coloured effect in addition to sparks
Robotic	Tube containing pressed composition	Very short duration silver sparks - used to simulate robot welding or metal/metal spark effect
Saxon	Comprises two tubes containing pressed composition with opening on side of tube joined co-linearly at a hub. Usually nail (or similar) through hub to solid support	Spinning effect - the typical "Catherine" wheel. Usually gold or silver - duration up to 25 seconds
Line Rocket	Tube containing pressed composition (usually cold-burning - based on Nitrocellulose) fixed to a wire running over the heads of the audience	Usually silver or gold the device travels along the wire over the heads of the audience. The wire is usually painted black so that it cannot be seen by the audience.
Airburst	Small unit containing bursting charge and metal powder (usually Titanium) supported by firing wire on an overhead truss or similar	An overhead burst of silver sparks. These devices are not used above the audience
Flame projector	Large bore tube usually containing Nitrocellulose powder	Produces short duration, low heat yellow/orange flame
Waterfall	Tube containing pressed composition	Erected vertically downwards or parallel to the ground - the effect is a curtain of sparks (usually silver) falling from a height vertically downwards (cf Gerb - where the sparks go upwards)

Type	Description	Effect
Smoke	Canister containing coloured smoke granules	Usually short duration (about 5 seconds) production of coloured smoke
Flashpot	Canister containing loose flash composition	Puff of smoke (usually white) and flash. The typical "genie" effect
Confetti Bomb (or other streamer types)	Tube containing small lifting charge and payload of confetti, streamers etc.	Similar in function to a mine - ejects the units into the air.
Whistles	Tube containing pressed composition	Produces whistle - duration approx. 3-5seconds
Stage Mines	Similar in construction (but smaller) to an outdoor mine. Tube with limited lifting charge and payload. Typical calibre 24mm - 50mm	Ejects short duration stars and/or other effects
Coloured Fire	Loose composition usually contained in firing assembly	Produces coloured flame
Ice Fountains	Tube containing lightly pressed composition usually based on Nitrocellulose	Produces column of sparks and/or coloured fire. The fountain burns with a cold (about 80°C) flame

Stage pyrotechnics usually come ready-assembled into some form of firing jig (e.g. GEM, Lunatech or Le Maitre proprietary systems) and merely require "plugging in". The advantage of this system for repeated shows, such as at Disney, is that set-up time is very short, and testing of the individual items may be done before the units are deployed. Permanent wiring is then used to connect the firing modules back to the firing box.

There are several different types of firing system in use including:

- Hardwired systems using 2-core wire;
- Hardwired systems using multicore cable;
- Code-based systems - where a firing code is sent around the whole system and triggers individual "addresser boxes" on each unit;
- Radio/microwave systems for remote firing.

I2.3 *AERIAL SHELLS AND MORTAR INSTALLATIONS*

I2.3.1 *Aerial Shells*

The most important item of a fireworks display is the aerial shell. A brief description and schematic of an aerial shell is included in *Section I2.1*.

The construction and functioning an aerial shell is further described below as it is particularly relevant for discussion on failure modes fault and event tree analysis.

A firework shell comprises a payload and a lifting charge and is fired from a mortar in the similar manner as an artillery shell or a gun.

The payload of the shell comprises stars (or other effects), a bursting charge (see below) and a time delay fuse to function the burst of the shell at a pre-determined time after launch.

Shells may be either spherical or cylindrical (the vast majority are spherical - especially those manufactured in China) and the lifting charge (usually blackpowder grain) may be contained in one of the following ways:

- Loose powder loaded into the mortar (rare);
- Powder contained within a plastic or paper bag attached loosely to the base of the shell;
- Powder contained within a plastic bag that is attached directly to a time fuse end of the shell covered with plastic, paper or foil protective cover. This is the shell design type proposed to be used in the Theme Park.

The initiating fuse (which may be piped match (a blackpowder on thread core within a paper case, or direct by electric igniter) is inserted into the lifting charge.

Upon lighting the fire from the initiating fuse ignites the lifting charge which in turn ignites the "delay fuse" which will later transfer fire to the shell bursting charge.

In some cylindrical shells (from Italy and Malta predominantly) there may be a branch of the initiating fuse which lights the delay fuse directly which in these cases may be at the top (rather than the bottom) of the shell. Such shells are termed "top-lit" and present additional failure modes - however their use is extremely rare and is not included in the present study.

The lifting charge expels the tube from the mortar. High speed film using transparent mortars indicates that initiation of the blackpowder lifting charge produces a large amount of fire in the tube, some of which passes by the shell (shells are usually quite a loose fit in a mortar - e.g. a 120mm OD shell in a 125mm ID mortar) and emerges from the top of the mortar tube. The shell then rises from the base of the mortar and is ejected into the air.

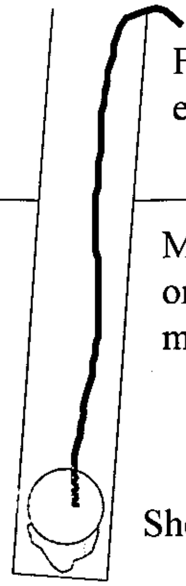


Figure I2.3a Shell in Mortar

Once the time fuse has burned through, the fire is transferred to the "bursting charge" of the shells - usually a charge of blackpowder or flash powder (see below) which explodes to both fragment the shell casing and light the stars or effects contained within the shell.

Flashpowder, or a mixture of blackpowder and flashpowder or similar, is a more energetic explosive than blackpowder itself and is often used to burst a shell because:

- fragmentation of the shell occurs more evenly leading to a better distribution of stars and a more regular pattern;
- a smaller quantity compared to blackpowder alone is required.

The chemical composition of flashpowders used for bursting shells varies but in general is composed of:

- An oxidant (usually Potassium Perchlorate - although Potassium Chlorate or Barium Nitrate may be used in special circumstances);
- An energetic fuel (usually finely divided aluminium or magnesium or a mixture of both).

The typical quantity of flashpowder used to burst spherical shells is given in *Table I2.3a*.

Table I2.3a Quantity of Flashpowder Used to Burst Spherical Shells

Shell diameter	Quantity of flashpowder
3"	50g
4"	75g
5"	100g

I2.3.2 ***Mortar Installations***

Typical mortar installations are shown in the following figures.

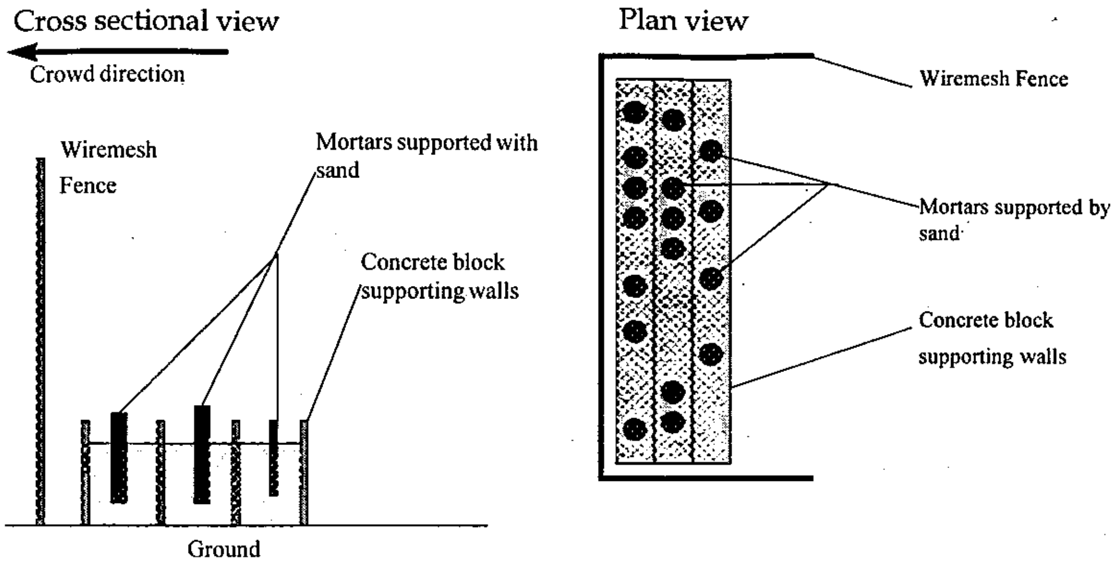


Figure I2.3b Mortar Buried in Sand in Concrete Trough (Semi-permanent /permanent installation)

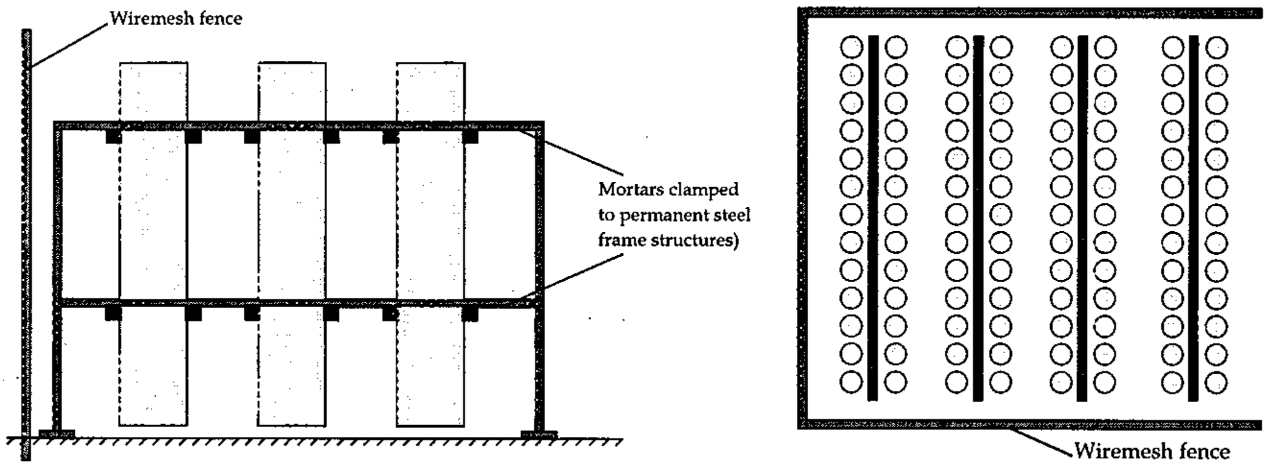


Figure I2.3c. Mortar in Steel Framed Launch Boxes (permanent installation)

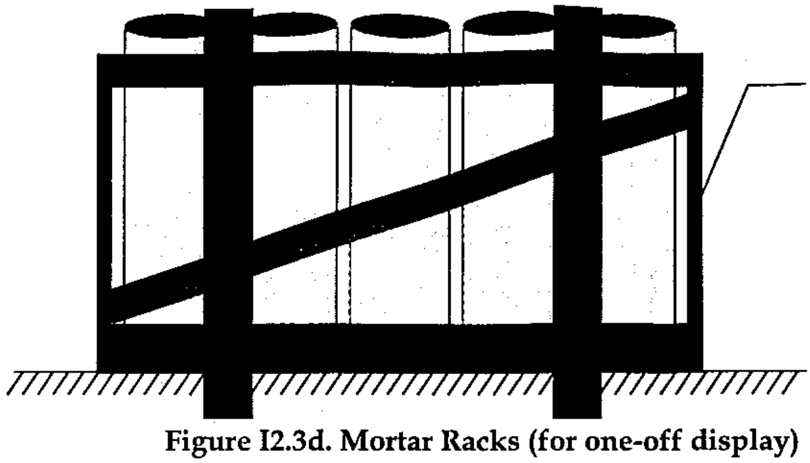


Figure I2.3d. Mortar Racks (for one-off display)

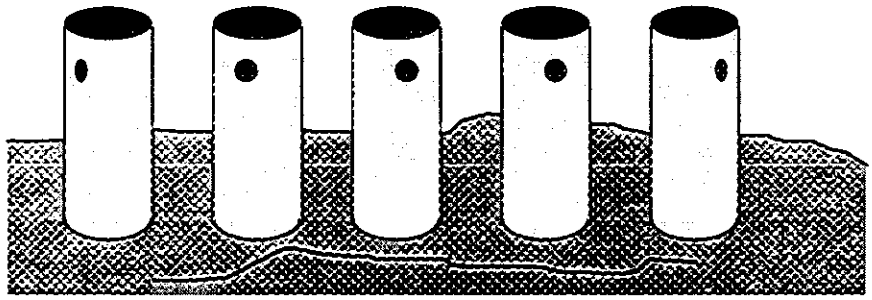


Figure I2.3e Mortar Buried Individually in Sand (for one-off display) or in Concrete (permanent installation)

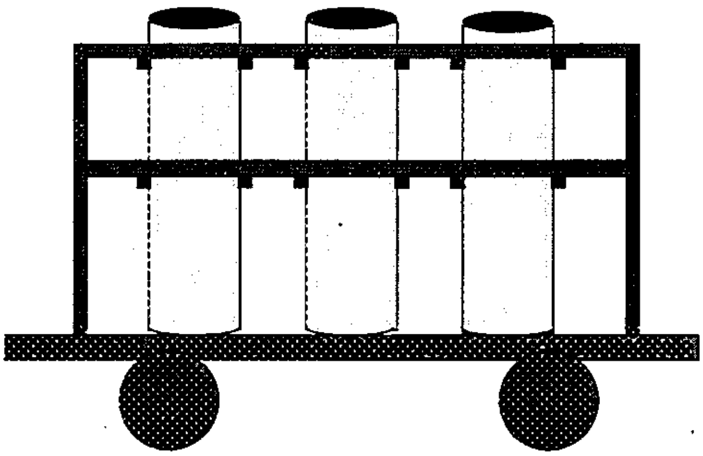
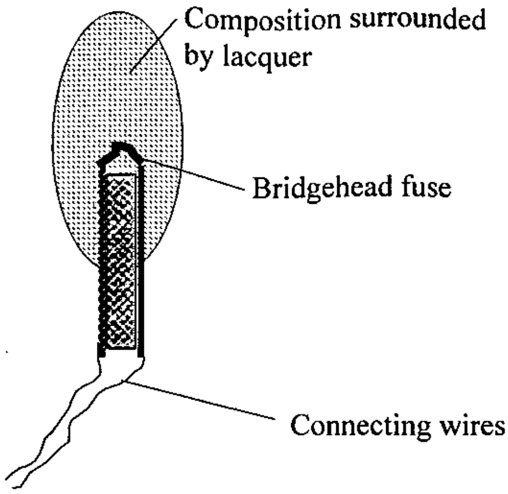


Figure I2.3f Mortars on a Trailer (semi-permanent installation or one-off display)

I2.4 *ELECTRIC IGNITERS*

All fireworks will be initiated by use of electric igniter (syn squib, electric match, igniter, electric fuse - NOT Detonator). In essence an electric igniter is a simple source of a spark - it comprises a bridge wire surrounded by composition and a lacquer sheath.



On application of current (typically supplied by 24V battery, or via a capacitor discharge system) the bridgehead fuse ignites the composition, which in turn ignites the firework to which the igniter is connected. It is important to stress that electric igniters are not Detonators - they are a source of ignition only and do not produce the detonative shock wave required to initiate high explosive.

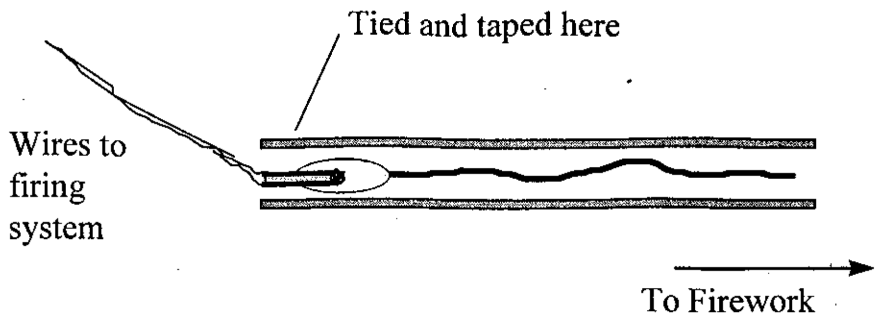
Igniters are, however, somewhat sensitive to friction or crushing, and care must be exercised in their handling and use to prevent these modes of unintentional initiation. For this reason igniters are typically enclosed in a plastic sheath - which not only gives some protection against accidental initiation, but also serves to direct the flame produced on ignition.

There have been concerns expressed around the world that igniters are especially sensitive to Radio Frequency (RF) induced current. Strong RF transmission sources such as permanent radio installations (e.g. Marine Radio - typical power about 4W) may cause accidental initiation of igniters. Even low-power RF sources (e.g. mobile telephones, portable "walkie-talkie" equipment - typical power about 1W) may have similar potential and therefore should not be used in close proximity to electric igniters.

Loose igniters are usually stored separately from the main firework/ pyrotechnic store. Fireworks or Pyrotechnics with igniters fitted may, however, be stored in the main store.

Igniters are attached to fireworks in one of two basic ways:

- The igniter is inserted into the normal firework fuse (usually "piped match" - see below), or into a piece of fuse attached to the firework for this purpose; or
- The igniter is inserted directly into the firework body - for instance, for precision of firing an igniter is frequently inserted directly into the lifting charge of a shell so that once initiated there is effectively zero delay time until the shell is launched.



Both methods will be employed by Disney.

The firing wires are then led back to the firing system either directly, or via attachment to a "rail" or "splitter box" arrangement - which in turn are then usually connected to the firing system by multicore cable.

Testing of the circuits is carried out by passing a very low current down each circuit and testing for continuity or resistance. Circuits can be connected in parallel or series - both have advantages and disadvantages.

The firing system may be of the following general types:

- Manual, individual button press systems triggered by the firer as he receives a cue;
- Semi-automatic, where sequential cues are fired automatically;
- Computer with manual over-ride - usually fired by MIDI or SMPTE timecode via an interface box. This system, of the general type indicated by Disney, permits isolation of, for example, specific shell calibres and/or types to remove them from firing as deemed necessary;
- Fully automatic.

In addition, the electric pulse required to fire a circuit can be relayed to the individual firework by:

- Direct discharge of a battery through a simple circuit;
- Discharge of a capacitor across a simple circuit;
- Coded firing, in which a coded signal is sent to individual "addresser" boxes attached to each firework or group of fireworks. The addresser box then triggers the firework directly by either direct battery or capacitor discharge;
- Radio systems.

I2.5 Possible Causes of Failure from Firework Types

Fireworks may fail to perform as designed or perform in an unsafe manner. *Table I2.5a* describes the failure modes for different types of fireworks.

Table I2.5a ***Fireworks Types and Possible Failure Modes***

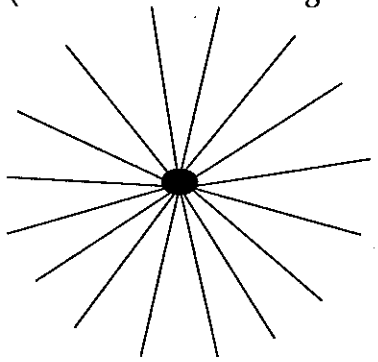
Type	Effect	Failure Mode
Shells	Shell is projected from a mortar either by pyrotechnic lifting charge or gas lift "Invisible" or deliberately accentuated flight into the air followed by Burst of shell casing and ejection of stars or units	1. Failure to ignite 2. Failure in/of mortar 3. Failure at mortar muzzle 4. Low burst 5. Failure to burst as designed 6. Initiation on impact (if 5) 7. Casing debris outside safety area 8. Debris from stars/pyrotechnic units outside safety area 9. Disruption of firing angle prior to firing 10. Fast moving, heavy object projectile hazard towards crowd (if 9)
Mines	Stars/Effect units projected from a mortar in a conical fashion(cf shell). Stars burn or units perform once ejected	1. Failure to ignite 2. Failure in/of mortar 3. Failure to ignite stars/units 4. Debris from stars/pyrotechnic units outside safety area 5. Casing debris outside safety area 6. Disruption of projection angle prior to firing
Roman Candles	Alternating stars/units and lifting charges designed to project the payload into the air over an extended period (typically 25-45 seconds)	1. Failure to ignite 2. Failure in/of tube 3. Debris outside safety area 4. Disruption of projection angle prior to firing
Multishot items - "Cakes" or "Box Items"	Multishot items usually composed of "single shot" Roman candle type units interconnected in a square or circular pattern - hence "cake" or "box". Usually comprises a mixture of stars, effects, noise units etc.	1. Failure to ignite 2. Failure in/of tube 3. Debris outside safety area 4. Disruption of projection angle prior to firing
Gerbs (Fountains)	Emits shower or showers of sparks from tube filled with solid composition	1. Failure to ignite 2. Sparks as debris 3. Disruption of projection angle prior to firing

Within these types, and especially the aerial types, there are a number of specific effect types that pose differing risks. Details of different shell types are given in *Table I2.5b.* The schematic of the special effects are shown below.

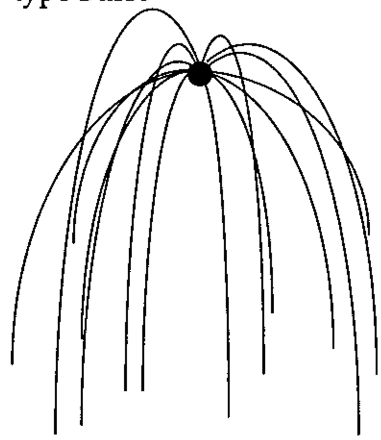
Table I2.5b ***Generalised Shell Effects and Potential Hazards***

General Type	Effect	Hazards
Colour and Colour change	Coloured stars, usually in a spherical burst pattern - see diagram below	Relatively quick burning and therefore of low debris risk
Pattern	Limited number of stars to form, say, a circle or spider's web pattern	May include longer burning stars - slightly increased risk from burning debris
Brocade, Kamuro, Crown, Willow	Deliberately long burning stars, usually of gold and/or silver, occasionally with colour change - see diagram below	Increased risk from burning debris
Effects	Includes all non-colour types e.g. Whistles, Screechers (Croakers) Bangers (Reports) Torbillions (Serpents) Falling Leaves Salutes (Maroons)	Possible debris from internal units. Salutes/Maroons are deliberately violent in their action (this is what produces the "bang") and therefore pose additional risks if the product fails to perform as designed.

Normal Star Burst
(Colour or colour change shell)



Willow/Brocade/Crown/Kamuro
type Burst



I2.6 TYPICAL DISPLAY DESIGN

The final design of any of the firework or pyrotechnics displays at the proposed site will be determined later. However the following typical displays illustrate the range of product used at Disney and other displays in the past.

Table 12.6a ***Breakdown of Typical Fireworks Display***

	Disney Magic Kingdom "Fantasy in the Sky" 1999	**Hong Kong Handover Display 31/6/97**	**Typical Medium scale aerial display using upto 5" Shells**
Approx. Duration	12 minutes	20 minutes	10 minutes
3" Shells		500	80
4" Shells	46	500	60
5" Shells	56	1200	40
6" Shells	96	1600	
8" Shells	18	250	
10" Shells		120	
12" Shells	1	60	
Mines		100	20
Roman Candles		500	30
Multishot items		300	10
Comets			30

Notes

1) *There is a maximum shell calibre of 5" at the proposed site*

2) *All figures are approximate*

3) *Hong Kong prohibits the firing of shells >12"*

For the purpose of this study, the number of aerial shells fired is assumed to be about 200 per show (mid-level display). The distribution of 3", 4" and 5" shells is assumed to be 0.5, 0.3 and 0.2 respectively.

I3 SAFETY REQUIREMENTS

The safety requirements for fireworks transport, storage and use can be classified in the following headings:

- restrictions on the class of explosives to be used for fireworks display;
- quality control in manufacturing;
- safety requirements for fireworks display, storage and transport;
- separation distances.

As explained in the main report, 1.3G and 1.4G explosives only are permitted to be used for fireworks display. Also, as explained in the main report, explosives in division 1.3 and 1.4 do not present a mass explosion hazard or a projectile hazard.

I3.1 QUALITY CONTROL

Disney currently adopt the following procedures regarding vendor quality and quality of fireworks products :

- Disney reviews samples from a vendor before qualifying them to even bid for supplying fireworks product. The samples are evaluated for construction, consistency of performance and display value;

- A vendor visit will take place either prior to as part of the first order placement. This is to evaluate the manufacturing process, capacity of the operation, review either samples or first articles from a pending order and get second view of the quality and consistency of the product;

- On receipt of goods from the vendor, a test is scheduled to review the product prior to placement into a show.

- On going review of product in shows takes place through daily show reports for all fireworks shows across the theme parks. Product problems are reviewed and acted accordingly.

As regards safety requirements and separation distances, these are described in the following paragraphs.

I3.2 SAFETY REQUIREMENTS FOR PRE-DISPLAY LOADING

During rigging the following precautions must be observed.

- All firing systems must have at least 2 levels of isolation of firing circuits (eg key and manual firing switch) and source of power (eg batteries) to be isolated during rigging phase;
- Electric igniters and connected circuits should be shunted (shorted) until testing and firing phase;

- Rigging should not take place during lightening storms;
- Care should be exercised in handling of igniters.

I3.3 *SAFETY REQUIREMENTS DURING THE DISPLAY*

Prior to the start of the display a decision must be made whether it is safe to fire the display, to fire a reduced display, or to cancel/postpone the display entirely. This decision will be made on the basis of:

- Predicted wind direction and strength at the proposed time of display;
- Other adverse weather conditions (e.g. fog, very heavy rain);
- Crowd control issues (e.g. crowd spilling into excluded areas).

During the display the following safeguards are in place.

a) It is possible to immediately stop the display if debris is falling onto the crowd or other protected area (e.g. explosive store);
b) It is possible to curtail the display by removing items (e.g. shells above a certain calibre or type);
c) Watchers are to be positioned such that they can observe the audience and vulnerable areas in order to report conditions to show control.

I3.4 *SAFETY REQUIREMENTS DURING DE-RIGGING*

It is likely that a small number over the period of several displays of fireworks will fail to ignite (e.g. shell on a "dead" circuit), or fail to function completely (e.g. partial functioning of Roman candle or multishot battery or failure of a shell fuse). These failures are term UNFIRED and MISFIRED respectively. These items must be rendered safe.

- There will be a "cooling off" period immediately post display to prevent injury to operators de-rigging the display
- Unfired/misfired items will be identified (e.g. by tape over mortar tube)
- Unfired items will be disconnected from firing system, wires shunted, items removed from mortars (in the case of shells), checked and returned to the store for later use.
- Misfired/partially fired items will be made safe (the best way to make any explosive safe is to function it) and not returned to the store. In some cases it may be practical and advisable to re-work an item (e.g. by adding new fuse) and then reusing the item. In other cases the item will have to have to be destroyed at a safe place.

I3.5 *UK OFFSITE SAFETY DISTANCES FOR STORAGE*

The safety distances required are dependent on the quantity of explosive to be stored and the maximum hazard of the explosive to be stored. For Hazard Division 1.3 Explosives the required distances are given in *Table I3.5a.*

Table I3.5a ***UK Offsite Safety Distances for Hazard Division 1.3***

Quantity of Hazard Division 1.3 Explosives (Net Explosive Quantity, NEQ)	Distance to low occupancy sites (e.g. roads, jetties, sports grounds etc.)	Distance to high occupancy sites (e.g. Houses, major roads, Schools, Theatres etc.)
1000Kg	32m	64m
1500Kg	36m	73m
2000Kg	40m	80m
3000Kg	46m	92m
4000Kg	50m	101m
5000Kg	54m	109m
6000Kg	58m	115m
8000Kg	64m	127m
10000Kg	68m	137m

Source UK Explosive Act 1875 Appendix K - modified

Table I3.5b gives comparative distances to high occupancy sites for explosives of Hazard Divisions 1.1, 1.2, 1.3 and 1.4.

Table I3.5b ***UK Offsite Distances for All Hazard Divisions***

Quantity (NEQ)	Distances			
	HD 1.1	HD 1.2	HD 1.3	HD 1.4
250Kg	60	60	40	24
500Kg	96	96	50	31
1000Kg	150	150	64	36
1500Kg	193	193	73	38
2000Kg	229	229	80	40
3000Kg	285	285	92	43
4000Kg	328	328	101	45
5000Kg	362	362	109	46
6000Kg	391	391	115	48
8000Kg	437	437	127	49
10000Kg	475	475	137	51

Source UK Explosive Act 1875 Appendix K - modified

The distances for 1.1 and 1.2 explosives are nowadays taken to be the same since the fragment effects from blast is considered to be more significant than the blast itself.

The UK regulatory authorities are presently revising the law relating to the storage and manufacture of explosives, and new regulations (The Manufacture and Storage of Explosives Regulations - MSER) are due to be in force in 2002/2003. These regulations may alter significantly the distances required from the table above. The following general points seem likely to be incorporated into new regulations:

- The regulations will specify Hazard Type (HT) not UN Hazard Division (HD) - see later;
- Distances for HT 1 and HT2 explosives may increase particularly for brick/concrete stores at lower quantities (<1000Kg);
- Distances for HT3 explosives may be reduced;
- A default minimum of 10m for HT4 explosives may be applied;
- Onsite safety distances will be reduced.

The above changes however, are not expected to have a significant impact on the requirements for the proposed fireworks store.

I3.6 SAFETY DISTANCES FOR DISPLAY

Outdoor Display

The safety requirements for fireworks display are laid in NFPA 1123 : Code for Fireworks Display.

The requirements contained within the NFPA code include a number of safety procedures in addition to minimum separation distances from the firing site to the spectators, as given in *Table I3.6a.*

Table I3.6a ***Minimum Separation Distances from Display Site to Spectators***

Mortar size (inches)	Minimum secured radius of display site	Minimum distance to spectators- vertical mortar	Minimum distance to spectators - angled mortar (1/3rd offset)
<3"	43m	43m	29m
3"	64m	64m	42m
4"	86m	86m	58m
5"	107m	107m	70m

The NFPA distances are based on the following factors:

- The debris distance for normal shell functioning;
- The burst radii of shells;
- The likely throw distance of a shell ejected from a mortar at its designed angle.

The NFPA distances are among the most conservative (ie greatest) world-wide. A comparison of minimum separation distances in the USA, the UK and Australia for a variety of items is given in *Table I3.6b.*

Table I3.6b ***International Safety Distances for Outdoor Fireworks***

Firework Type	US (NFPA Code) also Hong Kong	UK	Australia
3" Shell	56m	25m	30m
4" Shell	86m	37m	50m
5" Shell	107m	45m	70m
3" Colour Mine	62m	25m	30m
1" Roman Candle	46m	25m	30m
25mm Fountain	23m	25m	20m

Data sources:
USA - NFPA Code 1123 and PGI Guidelines
UK - British Standard BS 7114; part 2; 1988 and Industry Codes
Australia - Australian Firework Standard

For other firework types such as fountains, roman candles, wheels and set pieces (termed as ground display pieces in NFPA), the minimum distance shall be 23m from spectator viewing areas. For ground pieces with greater hazard potential (such as large wheels with powerful drivers, roman candle batteries and items employing large salutes), the minimum separation distances shall be 38m.

Indoor Display (Stage Shows)

The minimum distances for pyrotechnics display (ie stage shows) before a proximate audience as specified in NFPA 1126 are as follows:

- Each pyrotechnic device fired during a performance shall be separated from the audience by at least 4.6m but not less than twice the fallout radius of the device;

- Concussion mortars (maroons) shall be separated from the audience by a minimum of 7.6m;

- There shall be no glowing or flaming particles within 3m of the audience.

The UK Confederation of British Industry estimate that some 20,000 firework displays are carried out each year in the UK (see *Table I4a*). Such displays include both professionally fired displays, and displays staged by amateur firers (e.g. sports clubs, schools etc.) where the fireworks conform to the requirements of British Standard BS 7114; part 2; 1988.

Prior to 1997 the semi-professional displays would have used significant quantities of shells, but these were restricted from general supply in 1997 following new regulations.

Table I4a *No. of Displays in the UK*

Year	Amateur	Professional
1994 to 1996	36,000	24,000
1997 to 1998	-	16000
Total no. of shows	36,000	40,000
Avg. no. of shells per show	100	250
Total no. of shells	3.6×10^6	10×10^6

The number of shells fired vary depending on the audience. The recent Millennium celebrations in London fired 40,000 shells from 16 barges. An average of 100 shells for amateur display and 250 for professional display is assumed.

The number of reported accidents at large organised displays over the period 1993 to 1998 is given in *Table I4b*.

Table I4b *Fireworks Accidents in the UK (1993-1998)*

Year	Total number of reported accidents	Number of accidents at large organised displays
1998	831	132
1997	908	137
1996	1233	223
1995	1530	207
1994	1574	213
1993	1058	156

Data source - DTI Firework Injuries 1998

Of the 831 firework related accidents reported in the UK in 1998, 132 were at "large public displays". The severity of the accidents is measured by the level of treatment required. *Table I4c* provides details the treatment of 132 accidents at large public displays in 1998.

Table I4c *UK Data 1998 - Incidents at Large Public Displays*

Outcome	No of People
No further treatment required	54
Patient referred to doctor	14
Patient referred to hospital	37
Patient detained in hospital overnight	2
Patient transferred to another hospital	1
Died	0
Not known	23
Not specified	1
Total	132

(Source - DTI Accident Figures 1998)

Of these 132 injuries, 63 were to eyes and were indicated to be as a result of falling debris/ash from the display site. The data is consistent with that provided by Disney for displays at their theme parks over a 5 year period (see main report).

The results of UK HSE burn trials (as yet unpublished) on ISO containers containing fireworks are summarised in *Table I5a.*

Table I5a ***Results of UK burn trials on ISO containers containing fireworks***

Trial	Result	Comments
1000Kg gross mass of 1.4G fireworks ("Shop Goods" types in 20' ISO container lit externally	Fireworks start to ignite after approx. 7 minutes. Doors of container remain intact. Fire subsides and only restarts when doors opened.	Very minor effect. Fire restarts when doors reopened and oxygen allowed back into container to sustain combustion of cardboard boxes.
1800 kg gross mass of 1.3G and 1.4G fireworks including 57x8" shells, 60mm Roman candles and approx. 200 x unpacked (loose) rockets. ISO container lit externally	Fireworks start to ignite after approx. 7 minutes. Doors of container opened by pressure build up but not distorted. Complete consumption of contents in approx. 30 minutes.	Roman candle and shell stars ejected from container once door opened. Container integrity substantially unaffected by fireworks.
20 x 3" maroons in fibreboard box in corner of container #1 above. Lit by electric match into single maroon.	Communication between maroons (salutes) and disruption of structural integrity of container at corner where maroons were placed.	Bulk storage of 3" maroons "defaults" to 1.3G hazard in UK. Maroons above this calibre "default" to 1.1G
2600Kg NEC of 5" star shells 2/3 filling a steel ISO container. Remaining space filled with boxes of sawdust. External fire.	First functioning of firework after approx 6 minutes causes doors of container to open. Next shell burst ejects and ignites boxes of sawdust. Remaining boxes of shells then ejected and dispersed onto ground immediately in front of container. Rapid (c 10 seconds) ignition and functioning of shells leads to fireball	This is the "worst case" scenario devised by HSE. The container was substantially unaffected by the trial - minor buckling of side panels evident. No mass explosion event (as qualified by pressure measurements and physical examination of the trial site witness plates etc). This result is particularly relevant to the types and quantities of fireworks proposed by Disney. Expert opinion is that in a normal store (ie with corridor down centre of store for access to fireworks) the event would be less.

Source Unpublished data - Private communication with HSE

I6 HAZOP STUDY DETAILS

I6.1 DESCRIPTION OF KEYWORDS

The HAZOP study adopted a number of key words to examine the causes, consequences and safeguards. These are described in *Table I6.1a.*

Table I6.1a ***Keywords Used in HAZOP***

Keyword	Explanation and likelihood
Load Fall	Dropping of either a box of fireworks or an individual firework. The specific risks associated with dropping fireworks include ignition of fireworks by shock or friction. Initiation by this route is very rare.
Spontaneous Ignition	Spontaneous ignition of fireworks could occur through chemical incompatibility of the firework composition (this has essentially been eliminated through consistent practices throughout the World), or because of the introduction of some foreign agent into the firework - eg water or acid (which could react with metal powders inside the fireworks giving rise to local "hot-spots" and ultimately ignition, or strong oxidants (which could react with the fuels in a firework composition). These modes of failure are extremely rare in finished product, and are mainly of concern in manufacturing operations where large quantities of loose composition or stars may be present.
External Fire	External fire can be caused by a number of routes - vehicle fires, sabotage, smoking etc. It is essential to protect boxed and loose fireworks from external fire - especially in storage where fire spread between loose fireworks and boxed fireworks could be rapid.
Adverse Weather	There is a small risk of accidental initiation from adverse weather, for instance from lightning. It is normal best practice to cease operations during lightning storms - firstly because of direct initiation by lightning causing a fire, and secondly because of the increase risk of initiation of electric igniters in high static conditions. All stores should be bonded to earth, and all wires on igniters should be shunted until the firework is installed at its firing position.
Road Accident	A road accident, either when transporting bulk firework from the jetty to the store, or from the store to the firing area could initiate an external fire which spreads to the load. It is also possible that, for instance, roll-over of a vehicle onto loose or boxed fireworks could initiate a fire by the effect of friction on the composition of crushed fireworks. However this outcome is considered to be extremely unlikely.
Vehicle fault/fire	A fault or fire on a vehicle could initiate a fire spreading to the load eg a tyre fire. The short distances and relatively small loads to be carried make this scenario extremely unlikely.
External Initiation	External initiation of igniters is possible if current is induced in an igniter by high powered radio frequency fields (RF). This is discussed further below.
Vehicle Accident	A vehicle accident, perhaps not involving a vehicle used for transport of fireworks, could result in a fire spreading to the main store of fireworks.

Keyword	Explanation and likelihood
Unauthorised Access	Unauthorised access to the store - either deliberate or accidental - could result in a fire spreading to the load. The most likely cause of fire is from smoking which should be prohibited anywhere near where fireworks are being transported, stored or used.
Mixed Load	This can occur in two ways 1)Although normal storage rules do not prohibit the keeping of loose igniters with fireworks, good practice is to keep loose igniters in a separate store or in an annex to the main store. 2) Other dangerous goods (eg acids, oxidants) should not be transported with or stored with fireworks
Initiation	Direct manipulation of fireworks gives some risk of accidental initiation. For instance the fitting of igniters to fireworks poses a small risk through impact or friction on the igniter during this operation. Similarly cutting and joining of fuses poses a small risk of accidental initiation. These and other operations direct on fireworks should be carried out only at the display site, or a t a dedicated area - and never at the store where initiation of one fireworks could spread fire to the rest of the load. Handling fireworks within a store (eg "picking" items for a display) introduces a very small risk of accidental initiation from dropping, or as a result of loose powders being exposed in the store.
Pre-ignition	Mishandling (or careless handling) during the pre-rigging and rigging phase of a display could result in accidental initiation. The risks are very small, and the likelihood of fire spreading to the bulk storage are remote provided that the working area is away from the store and the store is closed.
Shell Failure	Shell failure can occur through several mechanisms and is discussed fully below. The accepted rate of failure of a shell in any manner is relatively low (1 in 1000) but this includes bursting at non-design height, incorrect delay time, or rarely bursting of the shell while it is still within the mortar. In the last case bursting of the shell may not rupture the mortar - it may merely eject the stars upwards (as in a mine) in which case the shell is termed a "flower-pot"
Mortar Orientation	A mortar could be angled incorrectly leading to an increased risk of the shell it fires travelling towards the audience. Small deviations from vertical are normal (it is common to angle all mortars about 5° away from the audience to decrease the chance of normal debris falling towards the audience and to ensure that a shell that fails to burst (termed a "dud", "blind" or "black" shell) lands away from the audience. Deliberate angling of mortars is often used to spread the display in the sky (eg when firing several shells together in a single sequence) - here the angle of spread is perpendicular to the audience. Large angle disruption (for instance by the failure of an adjacent mortar) is extremely dangerous and is discussed further below. It is however a extremely rare occurrence.

Keyword	Explanation and likelihood
Debris Drift	Once an aerial firework has burst the distance the debris travels (either casing debris, or the stars or other effects) is largely determined by the wind strength and the location of where the debris falls to earth is largely determined by the wind direction. The initial velocities from the functioning of the fireworks (eg the shell bursting and ejecting shell fragments and stars radially) has a limited effect.
Other Firework Failure	The failure of other fireworks in a display can present three distinct risks: a) The firework may discharge towards the audience either as a result of mis-orientation or failure. The power of non-shell fireworks means that debris is unlikely to reach the audience at normal safety distances b) The failure of one item could disrupt the functioning of an adjacent item c) The failure of an item could disrupt the angle of an adjacent mortar. However the low power of these items means that adjacent mortar disruption is unlikely.
Fireworks-unfired/mis-fired items	Accidents can occur during the de-rigging phase of a display. The most likely cause of accidents include: a) Failure to identify an unfired item which subsequently functions b) Failure to identify a misfired item which subsequently functions c) Accidental initiation of an shell when removing it from its mortar d) Accidental initiation of an unfired firework when removing the electric igniter e) Accidents during disposal of misfired items

Note The term fireworks is used for all fireworks/pyrotechnics in this study

I6.2 HAZOP RECORD SHEETS

The HAZOP record sheets which is a record of the HAZOP sessions is attached.

TABLE NO: 1 DOCUMENT REF: c1819\qra\hazid REVISION: 0

DOCUMENT TITLE: Hazard Identification for Transport, Storage & Display of Fireworks

ITEM: Unloading from Jetty and Transport by Road to Store

a) Load unloaded from container on barge to road vehicle at the jetty
b) Road vehicle licensed for transport of explosives
c) Unloading and transport will be carried out at night
d) Load size limited to 4te net explosive weight
e) Load will be unloaded from road vehicle into store
f) Unloading at jetty and at store will be manual
g) Deliveries expected to be about twice a month
h) Fireworks/pyrotechnics and ignitors may be loaded and transported together. Alternatively, ignitors may be received as a separate load.

TEAM MEMBERS: TS,VS

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Load fall	1) Human error/ accident while transferring load from barge to vehicle	1.1) Load may fall on water; if not recovered may into authorised hands 1.2) Load on recovery from water need to be assessed, dried or disposed off 1.3) Load fall on land may result in ignition; load on barge or vehicle may be affected	1.1a) Load to be recovered; if not possible, appropriate agencies must be informed; 1.2a) Procedures for disposal; 1a) Adequate lighting in the area; 1b) Good manual handling techniques, training	A1. Identify agencies to be contacted and establish mechanisms for reporting incidents of non-recoverable load
Load fall	2) Load fall during transport due to inadequate securing of load or vehicle door	2.1) Possible ignition leading to fire spreading to the vehicle load	2a) Proper stowage practices & training	
Load fall	3) Load fall while transferring from vehicle to store due to human error/accident	3.1) Possible ignition leading to fire spreading to the load on vehicle or to the store contents	3a) Manual handling techniques & training	
Spontan. ignition	4) Chemical reaction within load	4.1) Possible ignition spreading to vehicle load	4a) Quality control; Keeping load dry by appropriate UN packaging	

TABLE NO: 1 (continued) DOCUMENT REF: c1819\qra\hazid
ITEM: Unloading from Jetty and Transport by Road to Store

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
External fire	5) External fire in the jetty area	5.1) Fire spreading to the load	5a) No smoking 5b) Exclusion zone around jetty unloading area 5c) Safe practices; vehicle engine switched off during loading	
External fire	6) Collision of barge with sea wall or fire on board vessel	6.1) Possible ignition of load	6a) Procedures for docking particularly during adverse weather 6b) Approved barges used for transport	
Adverse weather	7) Lightning strike or static electricity causing ignition of load while unloading	7.1) Fire spreading to load	7a) Loading not to be carried out during lightning storm	
Adverse weather	8) High waves or rain resulting in increased risk of load fall during unloading	8.1) Fire spreading to the load	8a) Procedures for unloading under adverse weather conditions	
Road accident	9) Collision or roll over during transit	9.1) Possible ignition of load due to resulting fire on vehicle	9a) No overloading of vehicle 9b) Less likelihood of vehicles on road at night time to be affected 9c) Approved vehicles for transport	
Veh.fault /fire	10) Electrical fault, tyre fire, engine fire	10.1) Fire spreading to load	10a) Approved vehicles 10b) Well maintained vehicles 10c) fire extinguishers on board 10d) Driver training on emergency response	
Ext.initi ation	11) High powered radio frequency causing functioning of ignitors by induced current	11.1) Fire spreading to load		A2) Mobile phones, walkie-talkies not to be carried by personnel handling load

Data File: disney.hdf

TABLE NO: 1 (continued) DOCUMENT REF: c1819\qra\hazid

ITEM: Unloading from Jetty and Transport by Road to Store

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Vehicle accident	12) Vehicle on fire near the store due to collision or vehicle fault/fire	12) Fire spreading to store	12a) Store to be closed until vehicle is ready to unload 12b) Store location away from regular vehicle traffic areas on site 12c) Store fenced & supervised 12d) Vehicle to be parked about 6m from the store	

TABLE NO: 2 DOCUMENT REF: c1819\qra\hazid REVISION: 0

DOCUMENT TITLE: Hazard Identification for Transport, Storage & Display of Fireworks

ITEM: Storage

a) Storage for 4 metric tonnes of net explosive weight of fireworks/pyrotechnics
b) Ignitors may be stored in a separate compartment
c) Store to be constructed of reinforced concrete as per Commissioner of Mines requirements. No exposed metal inside store.
d) Store is fenced (6m away) and has security
e) Store is located in back of house at distances to public buildings/roads prescribed by the Commissioner of Mines
f) Store will contain only hazard divisions UN 1.3 and 1.4 explosives (fireworks/pyrotechnics)
g) Manual handling of goods inside store
h) Stacking height will not exceed 2m to accommodate safe manual handling
i) No smoking, no naked flame inside or near the store
j) No combustible material outside of the store within the fenced area
k) Lighting inside store to be approved type
l) Earth mound towards the road as part of the park development
m) Inventory checking to ensure storage limits not exceeded
n) Storage practices to include stock rotation

TEAM MEMBERS: TS,VS

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Load fall	13) Human error/ accident while transferring goods into/from the store	13.1) Possible ignition leading to fire spreading to store contents	13a) Manual handling techniques/training	
Load fall	14) Improper stacking of goods	14.1) Possible ignition leading fire spreading to store contents 14.2) Possible ignition due to impact/friction on ignitors integral to the fireworks 14.3) Possible ignition due to impact/friction of fireworks composition eg in stars (less likely as compared to the former)	14a) Stacking practices	
Spontan. ignition	15) Chemical reaction within load	15.1) Fire spreading to load in store	15a) Quality control; Keeping load dry by appropriate UN packaging	

Data File: disney.hdf

TABLE NO: 2 (continued) DOCUMENT REF: c1819\qra\hazid
ITEM: Storage

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
External fire	16) Lit debris from fireworks display 17) Low bursting shell near the store 18) Shell trajectory misdirected towards store	16.1) Possible ignition of load in store 17.1) As 16.1 18.1) As 16.1		A3) Store to be kept closed during display
External fire	19) Vehicle fire adjoining the store	19.1) Fire spreading to load in store	19a) Fencing at 6m from store and no vehicles allowed inside fenced area 19b) Access to store area restricted to authorised vehicles	
External fire	20) Fire spread from adjoining dangerous goods or other goods stores or offices	20.1) Possible fire spread to the fireworks store	20a) Separation distances from fireworks store to adjoining store/office buildings in back of house	
Adverse weather	21) Lightning strike	21.1) Possible ignition of load in store	21a) Lightning conductor 21b) Suspension of operations within store during lightning unless required to do so for safety reasons	
Adverse weather	22) Flooding of store	22.1) Possible ignition of load in store due to chemical reaction of fireworks compositions with water	22a) Store location and design to consider potential flooding	
Ext.initi ation	23) High powered radio frequency causing functioning of ignitors by induced current	23.1) Possible ignition of load in store		A2) Mobile phones, walkie-talkies not to be carried by personnel working inside store
Unauthori sed acces	24) Security or management system failure	24.1) Malicious or accidental ignition of store contents	24a) Entry to public into backhouse prohibited 24b) Entry to store area restricted to authorised Disney staff	
Mixed load	25) Incompatible goods - eg. loose ignitors stored with fireworks/ pyrotechnics	25.1) Increased chance of ignition of load	25a) Separate ignitor store 25b) Proper labelling of packages 25c) Safety management to address storage issues	A4) Ensure ignitors are not stored with the bulk of fireworks/ pyrotechnics

TABLE NO: 2 (continued) DOCUMENT REF: c1819\qra\hazid
ITEM: Storage

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Mixed load	26) Incompatible loads - eg other dangerous goods such as oxidisers, acids etc	26.1) Increased risk of ignition through chemical reaction	26a) No other dangerous goods to be present in the store 26b) Proper labelling of goods 26c) Safety management	
Initiatio n	27) Manipulation of fireworks inside store eg. adding electric ignitors	27.1) Accidental ignition leading to fire spread to store contents	27a) No manipulation of fireworks to be carried inside store	A5) The site for manipulation of fireworks to be identified. The site should be located at adequate safety distance from the store
Initiatio n	28) Handling of items within store eg, taking individual shells out of boxes	28.1) Possible ignition leading to fire spread to store contents	28a) Minimise number of open boxes 28b) General good housekeeping eg. procedures for handling spilt pyrotechnic composition	A6) Procedures to be developed to minimise unnecessary handling/sorting of products for fireworks show inside the store. This should include adequate labelling of both outer packaging and product to aid easy identification

TABLE NO: 3 DOCUMENT REF: c1819\qra\hazid REVISION: 0

DOCUMENT TITLE: Hazard Identification for Transport, Storage & Display of Fireworks

ITEM: Fireworks Display

a) This includes
- pre-rigging (eg. fitting ignitors)
- rigging (installation of fireworks in to firing positions, connection & testing of electrical circuits),
- firing
- de-rigging (inspection & making safe of firing area, removal of unfired or misfired products, disposal)

b) Pre-rigging may be done on display site prior to firing or in a dedicated area away from the store
c) Rigging should be done on display site
d) Wiring must be done with no power source attached to the firing system
e) Testing must be done only when the display area is clear of personnel
f) Firing site is separated from spectator areas/public roads, buildings etc by adequate distances
g) Firing site is separated from dangerous good stores and other site buildings by adequate distances
h) Mortars must be secured in such a way that they do not suffer disruption from the failure of an adjacent firework
i) A mid-level show may contain up to 1000 separate firings and separate mortars.
j) A mid-level show may include both aerial shells and other fireworks devices such as comets and mines
k) A low-level show is likely to include comets and mines
l) A stage show will include only pyrotechnics articles designed for use in proximate audience.
m) There will be adequate 'cool-off' period before de-rigging .
n) Inspection & making display site safe includes identifying unfired items and misfired items
o) Unfired items may be taken to store while misfired items may have to be disposed off safely

TEAM MEMBERS: TS,VS

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Load fall	29) While transferring fireworks to pre-rigging area or display site	29.1) Possible ignition leading to fire spreading to load	29a) Operator training & procedures for handling & transport	A7) If vehicles such as fork lift trucks are used for transfer, it should meet appropriate specifications.
Ext.initi ation	30) High powered radio frequency causing functioning of ignitors by induced current	30.1) Fireworks functions in inappropriate location, orientation and time 30.2) Possible injury to public 30.3) Possible fire spread to store contents or other buildings on-site	30.3a) Fireworks store should be closed during pre-rigging/rigging 30a) Operator training 30b) Fireworks to be installed in to mortars or other equipment in their firing position	A2) Mobile phones, walkie-talkies not to be carried by personnel undertaking pre-rigging & rigging operations

TABLE NO: 3 (continued) DOCUMENT REF: c1819\qra\hazid
ITEM: Fireworks Display

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Initiatio n	31) Firing system live during installation	31.1) As 30.1, 30.2 & 30.3	31a) All power must be removed before rigging 31b) Procedures for checking	
Initiatio n	32) Un-intentional ignition during testing	32.1) Fireworks functions in inappropriate time 32.2) Safeguards for display may not be in place; possible injury to public	32a) Operating procedures 32b) Maintenance & testing of equipment	
Pre-ignit ion	33) Unintentional ignition while pre-rigging or rigging due to mishandling	33.1) Fireworks functions in inappropriate location, orientation and time 33.2) Possible injury to public 33.3) Possible fire spread to store contents or other buildings on-site	33.3a) Fireworks store should be closed during pre-rigging/rigging 33a) Operator training 33b) Fireworks to be installed in to mortars or other equipment in their firing position	
Shell failure	34) Premature burst within mortar eg. due to failure of shell delay fuse	34.1) Shell ignites within tube & mortar ruptures; possible disruption of adjacent mortars leading to unsafe orientation of adjacent mortars; 34.2) Shell ignites within tube (flower pot)	34.2a) Separation distances to crowd/ stores/ buildings conforming to display requirements should be adequate for this consequence 34.1a) Mortar design & installation such that failure of adjacent mortars minimised 34.1b) Only mortars of HDPE/GRP/Fibreboard/aluminium used as they do not present fragment hazard	

TABLE NO: 3 (continued) DOCUMENT REF: c1819\qra\hazid
ITEM: Fireworks Display

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Shell failure	35) Shell bursting at low height due to insufficient lifting charge, incorrect mortar size (ie 3" shell in 4" mortar) or strong winds	35.1) Shell ignites on or near ground level 35.2) Shell ignites at low (non-designed) height ie low burst; potential for burning debris affecting crowd	34.1a) Separation distances to crowd/ stores/ buildings conforming to display requirements should be adequate for this consequence 35a) Quality control 35b) Operator training & familiarity with products 35c) Moderate/ postpone or cancel the display in adverse conditions	
Shell failure	36) Shell ejected from mortar but fails to burst due to delay fuse failure	36.1) Shell lands in the display site & ignites on impact; possible minor injury to spectators (due to stars or burning debris) due to closer separation 36.2) Likelihood of shell landing in crowd due to wind drift is considered to be very low as separation distances are adequate for this scenario	36a) Quality control	
Shell failure	37) Shell bursts higher than designed height due to excess lifting charge	37.1) Possible further drift of debris	37a) Quality control	A8) The maximum height of typical 4" & 5" shell could be 150m & 175m resp.. The 4" & 5" shells for this display site should be designed specifically to meet performance requirements A9) Disney's vendor supply of 4" & 5" shells must ensure items destined for other Disney locations are not delivered in error to this site unless conforming to requirements of this site

TABLE NO: 3 (continued) DOCUMENT REF: c1819\qra\hazid

ITEM: Fireworks Display

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Mortar orientatn	38) Mortar angled incorrect (towards spectators) due to failure of mechanical system or procedures	38.1) Shell functions normally but bursts at low height or on or near ground level 38.2) Shell fails to function & lands in display area & bursts on impact spreading stars & debris to spectator area 38.3) Shell fails to function & lands in crowd & causes impact injury 38.4) Shell fails to function & lands in public area & ignites on impact causing local fire injury	38a) Supervision & adherence to procedures	A10) Procedures to be written if trailers are used A11) The mechanical system should be designed such that it does not result in mortars orientated towards spectators A12) Use of permanently installed mortars to be considered
Mortar orientatn	39) Disruption of mortars from adjacent shell failure - single or multiple mortars may be dis-oriented	39.1) Shell functions normally but ignites at low height or on or near ground level 39.2) Shell fails to function & lands in display area & ignites on impact spreading stars & debris to spectator area 39.3) Shell fails to function & lands in crowd & causes impact injury 39.4) Shell fails to function & lands in public area & ignites on impact causing local fire injury	39a) Design and installation of mortars such that adjacent shell failure does not cause mortar disorientation 39b) Fencing to contain low trajectory shells	A13) Design & position of fence to ensure containment of low trajectory shells towards spectators on site as well as road (off-site)
Debris drift	40) Wind strength and/or direction outside permitted levels	40.1) Debris falls on crowd: minor injury to spectators	40a) Monitoring of wind speed & direction prior and during the display 40b) Procedures for moderating (eg removing items such as larger calibre shells or long duration stars from the display), cancelling or postponing display	A14) The weather conditions under which fireworks display need to be moderated should be identified in procedures based on site layout & weather data. The procedures to also identify persons responsible for such decisions

TABLE NO: 3 (continued) DOCUMENT REF: c1819\qra\hazid
ITEM: Fireworks Display

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Other FW failure	41) Product not conforming to specification or incorrect installation	41.1) Possible disruption of adjacent fireworks. No significant consequence to spectators directly because of adequate separation distances	41a) Display site design & installation to ensure no risk of disrupting mortars containing shells	
Other FW failure	42) During low-level/ stage show due to product not performing to specification or incorrect installation	42.1) Burning matter/ debris on crowd	42a) Separation distances to crowd from display area 42b) Installation designed such that items cannot fall over or fail towards crowd 42c) No aerial shells are included in low-level or stage show	
FW-UNF/MISFRD	43) Fireworks remaining in position (unfired or misfired) after display is finished due to adverse weather effects before firing or show moderated or electrical failure or product failure	43.1) Fireworks could ignite after the display time while operator is inspecting the site; injury/death to operator 43.2) Fireworks ignites because of operator action; possible injury/death to operator 43.3) Fireworks require assessment & possible disposal	43a) Cooling-off period before inspection 43b) Operator training	A15) Procedures for safe handling & disposal of unfired & misfired items to be evolved
FW-UNF/MISFRD	44) Discharged fireworks found within display site or elsewhere	44.1) FW could be ignited by impact/ external force/fire etc 44.2) FW could be found/ collected by unauthorized personnel	44a) Sweeping of the site immediately after the display and/or the following day	A16) Procedures to be established for sweeping site after display

I7 SHELL BALLISTIC CALCULATIONS

Equations for the trajectory of a shell both within the mortar and after leaving the mortar have been published by Dr Shimizu [1]. There are a number of factors that determine the trajectory of a shell and these include shell characteristics such as type of shell - spherical or cylindrical, shell diameter, shell weight, grain size of lift charge, mortar characteristics such as mortar length, dead volume (unoccupied volume below a shell in a mortar), shell clearance within mortar and wind characteristics.

The Consultants have used simple projectile equations to determine the trajectory of a shell based on initial velocity. Different mortar angles were assumed and the trajectory calculated for three different shell sizes 3", 4" and 5". The parameters calculated are maximum shell height, maximum horizontal distance, and time of flight.

In reality, the actual trajectory is found to be little different from the predicted trajectory (based on theoretical calculations) and this is termed as 'drift' distance. The reason aerial shells drift is not completely known (one of the known causes is tumbling or spinning of the shell) but the drift distances were found to be about 30 to 40m for 4 " and 5" shells based on experimental results. To account for this effect, the drift distance is calculated from predicted travel time and wind speed (assumed 5m/s) and added to the predicted maximum horizontal range as shown in *Tables I7b, I7c* and *I7d* below.

The behaviour of a shell in flight depends on its shape. A shell in flight is acted on a by a lift force normal to its trajectory (in addition to gravity) and a drag force along its trajectory. In this case the shell is a sphere with equal dimensions along all axes and can be considered as 'chunky'. Such fragments or projectiles do not have a lift coefficient and hence only a drag effect exists.

The trajectory of a projectile is acted upon by a drag force which is proportional to either its velocity or square of its velocity (as in this case). This distinction is made on the basis of the Reynolds number which indicates the type of flow in a fluid (air in this case). For a projectile subject to a resistance proportional to the square of the velocity, the equations of motion are given below.

1 Kosanake KL and BJ Shimizu Aerial Shell Ballistic Predictions (Part 1 & 2), Selected Pyrotechnic Publications of KL and BJ Kosanke, Part 2

$$\frac{d^2x}{dt^2} + k\left(\frac{dx}{dt}\right)^2 = 0$$ *Equation 1*

$$\frac{d^2y}{dt^2} + k\left(\frac{dy}{dt}\right)^2 + g = 0$$ *Equation 2*

where,

x: horizontal displacement of the projectile
y: vertical displacement of the projectile
t: time
k: resistance proportionality constant
g: acceleration due to gravity.

The equations can also be written as

$$\frac{dv_x}{dt} + kv_x^2 = 0$$ *Equation 3*

$$\frac{dv_y}{dt} + kv_y^2 + g = 0$$ *Equation 4*

where,
v_x : horizontal velocity component
v_y : vertical velocity component

Equation 1 can be rearranged as

$$\frac{dv_x}{dx} + kv_x = 0$$ *Equation 5*

Solving Equation 5 we get

$$v_x = v_i \cos\theta \exp(-kx)$$ *Equation 6*

$$x = \frac{1}{k}\ln(1 + v_i \cos\theta kt)$$ *Equation 7*

where
v_i: initial velocity of the missile, and
θ: angle of inclination from the horizontal

Similarly solving for the vertical component, we get the following results

$$v_y = \sqrt{\frac{1}{k}(kv_i^2 \sin^2\theta + g)\exp(-2ky) - \frac{g}{k}}$$ *Equation 8*

for time of flight,

$$t = \frac{-1}{\sqrt{kg}}\left[\tan^{-1}\sqrt{\frac{k}{g}}v_y - \tan^{-1}\sqrt{\frac{k}{g}}v_i \sin\theta\right]$$ *Equation 9*

The value of k is estimated from the following equation

$$k = \frac{1}{2M}\rho C_D A_D$$ *Equation 10*

where,

ρ : density of air (kg/m^3)
C_D : drag coefficient [1]
A_D : drag area
M : mass of shell (kg)

Table I7a ***Shell Parameters***

Shell Diameter (in)	Mass (kg)	Display height (m)	Initial Velocity (m/s)	k(per metre)
3″	0.25	75	46	0.00445
4″	0.5	100	55	0.0041
5″	0.75	100	56	0.00436

The initial velocity is back calculated from the above equations based on the display height which is the maximum shell height for vertical firing.

The results are presented in the following tables.

(1) Value obtained from standard reference books in physics dealing with projectiles. Typical values for spherical objects vary from 0.4 to 0.5

Table I7b *Flight Parameters for 5 inch Shells*

Angle of Inclination (from Horizontal in degrees)	Maximum Height attained (m)	Time to Maximum Height (seconds)	Total Time of Flight (seconds)	Maximum Horizontal Range (m)	Maximum Horizontal Range (Adjusted*) (m)
5	2.2	0.5	1	59	64
10	5.7	0.98	1.96	92	102
15	11	1.44	2.87	121	135
20	18	1.86	3.71	143	162
30	35	2.58	5.16	170	196
35	44	2.88	5.76	177	205
40	53	3.14	6.28	179	210
45	61	3.37	6.73	177	211
50	70	3.56	7.12	172	208
60	83	3.85	7.71	152	191
70	93	4.05	8.1	119	159
75	97	4.12	8.24	96	137
80	99	4.16	8.33	70	111
85	101	4.19	8.38	38	80
90	101	4.2	8.4	0.0	42
95	101	4.19	8.38	-45	-3

* Adjusted for wind drift assuming 5 m/s

Table I7c *Flight Parameters for 4 inch Shells*

Angle of Inclination (from Horizontal in degrees)	Maximum Height attained (m)	Time to Maximum Height (seconds)	Total Time of Flight (seconds)	Maximum Horizontal Range (m)	Maximum Horizontal Range (Adjusted*) (m)
5	2.2	0.49	0.98	58	63
10	5.6	0.96	1.92	91	100
15	11	1.41	2.83	119	133
20	18	1.83	3.66	142	160
30	35	2.56	5.11	170	195
35	43	2.86	5.72	177	205
40	52	3.12	6.25	179	210
45	61	3.35	6.7	178	211
50	69	3.55	7.1	173	209
60	82	3.85	7.71	153	191
70	92	4.06	8.11	119	159
75	96	4.13	8.25	96	137
80	99	4.17	8.35	69	111
85	100	4.2	8.4	37	79
90	101	4.21	8.42	0	42
95	100	4.2	8.4	-44	-2

* Adjusted for wind drift assuming 5 m/s

Table I7d *Flight Parameters for 3 inch Shells*

Angle of Inclination (from Horizontal in degrees)	Maximum Height attained (m)	Time to Maximum Height (seconds)	Total Time of Flight (seconds)	Maximum Horizontal Range (m)	Maximum Horizontal Range (Adjusted*) (m)
5	1.9	0.42	0.83	46	50
10	4.4	0.82	1.65	70	78
15	8.3	1.21	2.43	92	104
20	13	1.58	3.16	110	126
30	26	2.22	4.45	134	156
35	33	2.5	4.99	140	165
40	40	2.74	5.48	143	170
45	47	2.95	5.9	142	171
50	53	3.13	6.27	138	169
60	64	3.42	6.84	122	156
70	72	3.62	7.23	94	130
75	75	3.68	7.36	76	112
80	77	3.73	7.46	54	91
85	79	3.76	7.51	29	67
90	79	3.76	7.53	0	38
95	79	3.76	7.51	-33	4

* Adjusted for wind drift assuming 5 m/s

The results were compared with the results calculated by Dr Shimizu [1] which is presented below. The results are found to be broadly comparable.

Initial velocity given in *Table I7a* is much higher due to greater display heights obtained in typical displays. A typical 5″ shell attains a height of 150 to 175m, 4″ shell a height of 100 to 150m and 3″ shell a height of 75 to 100m [2]. For the proposed Theme Park, Disney have however, opted to limit the maximum display heights for shells to values presented in *Table I7a*.

Table I7e ***Shell Performance by Dr Shimizu***

Shell size (in)	Muzzle velocity (m/s)	Maximum pressure (psi)	Distance to max. pressure (in)	Max. shell height (m)	Time to max. height (s)	Velocity on impact (m/s)	Time on impact (s)
3″	109	70	7.5	143	4.4	25	6.5
4″	110	114	7.4	182	5.1	30	7.2
5″	113	127	8.3	207	5.5	33	7.6

1 Kosanke, K.L and Kosanke, B.J., Shimuzu Aerial Shell Ballistic Predictions (Part 1), Selected Pyrotechnic Publications of K.L and B.J. Kosanke, Part 2.

2 Wharton R K Observations on the Heights Attained by Spherical Firework Shells, Journal of Pyrotechnics, Issue no. 1, Summer 1995

The fault tree and event tree for fireworks display are shown in *Figure I8a* and *I8b* respectively. The values used for quantifying the basic events in the fault tree and the branch probabilities in the event tree are described in *Tables I8a* and *8b* respectively. The assumptions or basis for deriving these values are also explained.

Table I8a ***Fault Tree Basic Event Frequency/ Probability***

Event	Description	Frequency or Probability of event	Comments
Unsafe mortar orientation prior to loading shell	The probability of mortar orientation prior to firing is not as designed (ie mortar orientation is greater than 5 degrees from vertical)	1×10^{-4}	Unsafe orientation may occur due to a number of reasons and these include displacement due to firing, incorrect installation following maintenance or redesign of the show or mechanical failure. Given value based on experience. It is equivalent to one mortar (amongst 200) being out of design orientation every 50 shows.
Operator fails to rectify before loading	Human error	0.1	Standard human error probability for checking routine tasks.
Mortar support failure during firing	The probability of mortar support failure	0	For the mortar arrangement typically used by Disney, the potential for mortar support failure is not considered.
Shell in mortar X fails	The probability of failure of some type in shell	0.001	Based on observations during firing and routine firing of test shells, the probability of shell failure (eg. Early burst) is less than 1 in 1000.
Mortar X ruptures	The failure of shell causes mortar X to rupture	0.1	This will only occur if shell fails within mortar X (ie other failure modes outside the mortar are discounted). In many cases the failure of a shell in a mortar will not lead to rupture
Mortar Y orientation disrupted resulting in unsafe orientation	Mortar Y is "knocked over" to a significant angle (greater than 5 deg from vertical) by the rupture of adjacent mortar X	0.1	Small angle deviation will not result in an unsafe discharge of the shell in mortar Y. Since mortar installation will involve permanent supports, the chance of disruption is considered to be low.

Figure I8a : Fault Tree for Shell Fired from Mortar in Unsafe Orientation

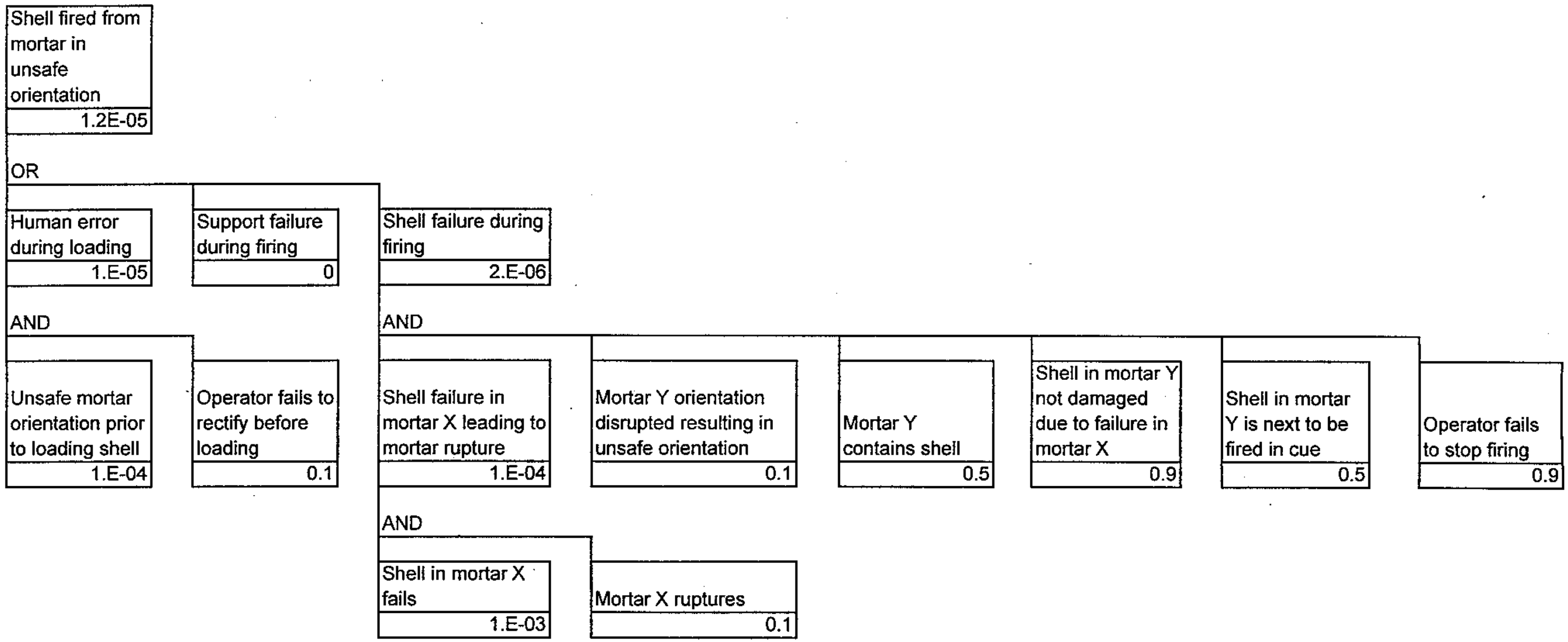
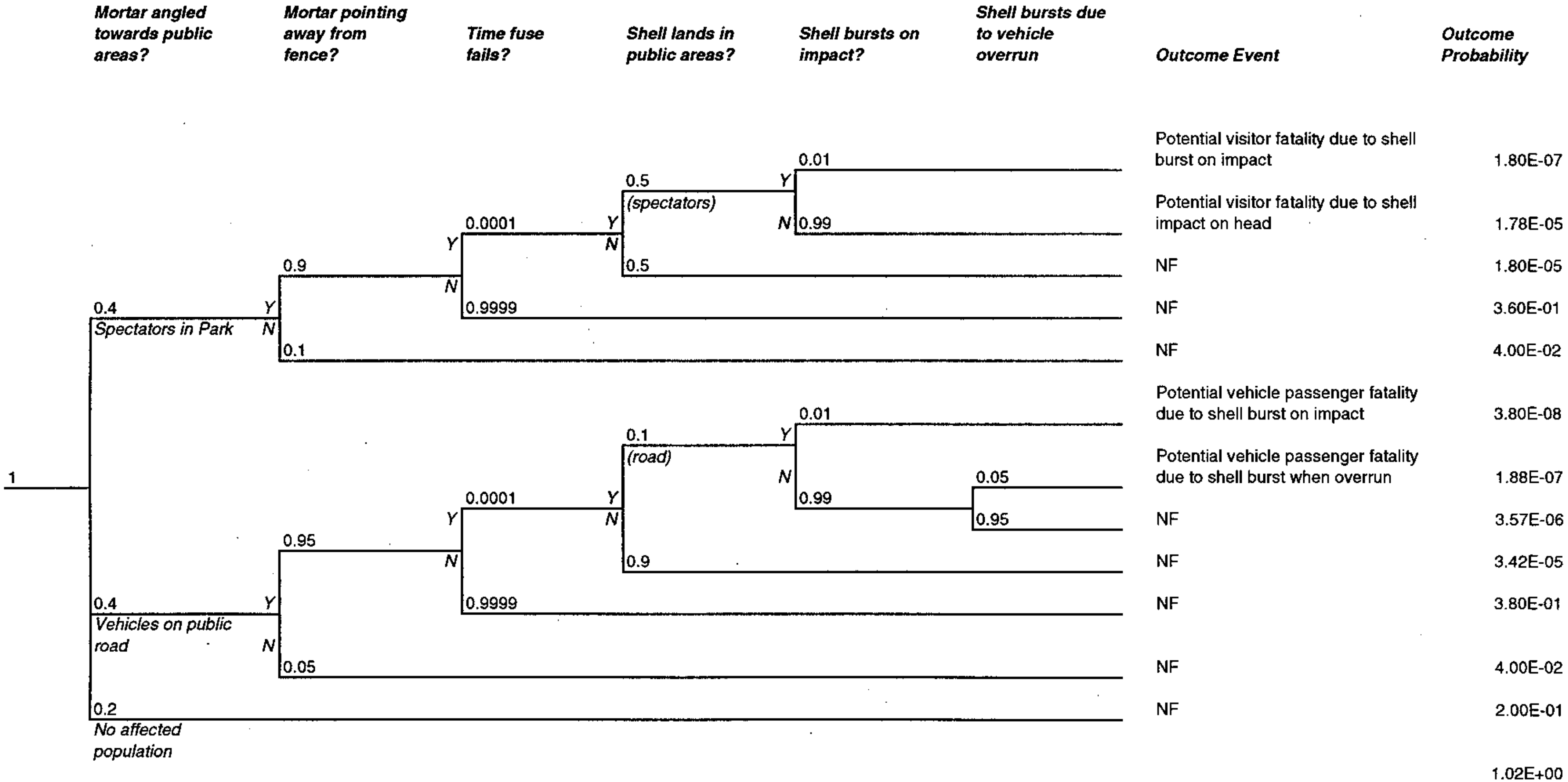


Figure I8b : Event Tree for Shell (fired from mortar in unsafe orientation) Landing in Public Areas



Event	Description	Frequency or Probability of event	Comments
Mortar Y contains shell	Does mortar Y contain a shell	0.5	In normal sequences firing proceeds linearly from one end of the firing site to the other. Hence, probability of 0.5 considered.
Shell in mortar Y not damaged due to failure in mortar X	The probability of shell remaining intact so as to function normally	0.9	There is a high chance that shell in mortar Y remains intact.
Shell in mortar Y is next to be fired in cue	The shell in an adjacent mortar may not be fired until much later in the display	0.5	Sequences of shells by size can mean that adjacent mortars are not fired sequentially. A 50% probability is assumed.
Operator fails to stop firing	Human error	0.9	If the operator stops the display before the firing of the shell in mortar Y then the shell in mortar Y poses no threat. Firing is done in cues. The average time between cues is about 6 seconds. Even if the firing system is automatic, operator can over-ride to stop the display. However, operator response may not be quick enough to stop the immediate next cue.

Table I8b ***Event Tree Branch Probabilities***

Event	Description	Branch probability	Comments
Mortar angled towards public	Is the mortar pointing towards an area of population or into a "dead" area?	0.4	The affected length (road or spectator areas) accounts for 40% of the total perimeter of the display site
Mortar pointing away from fence	Is the mortar pointing towards the wiremesh fence, or is it pointing over the fence?	0.95	It is assumed that any disruption of a mortar will leave it at an angle above the fence. This is conservative since mortars angled towards the fence will be contained by the fence.

Event	Description	Branch probability	Comments
Time fuse fails	The delay fuse between the normal lifting charge and bursting charge of the shell	0.001	If the normal time fuse is still burning the shell will function at its design time (typically 3-4 seconds after launch). If it is not functioning the shell will continue to travel towards the audience. The probability of delay fuse not functioning is considered to be very low based on observations during testing & firing.
Shell lands in public areas	Whether the shell lands on crowd within the Theme Park or on road outside the park	0.5 (0.1)	Within the Park, the areas in which the shell may land include buildings/covered structures of the park. A 50% probability is assumed. When a mortar is directed towards road, the probability that the shell will land within a 15m wide road is estimated as 10% (see *Section 7* in this annex).
Shell bursts on impact	The shell may function as a result impact with the ground or transfer of fire from the delay fuse but after the intended time	0.01	The probability of a shell igniting due to impact or due to delay fuse functioning after the intended time is assumed as 0.01. This is based on observations during handling and display.
Shell bursts due to vehicle overrun	Whether the shell that lands on road and does not burst on impact can burst due to vehicle overrun	0.25	The probability of this event is considered as the product of the probability of vehicle overrunning a shell (0.1) due to driver failure to take evasive action and the probability of initiation due to overrun (0.5).

The fault tree for 'operator error resulting in mixing of acid and hypochlorite' and subsequent chlorine release is shown in *Figure I8c*. The explanations are provided in *Table I8c*. The generic human error probabilities used for assigning values to the basic events in the fault tree is given in *Table I8d*.

Table I8c ***Fault Tree Basic Events***

Event	Description
Driver drives the tanker to the wrong tank	The driver is assumed to be familiar with the site. There will also be road signs leading the driver to the appropriate area. The driver may however, make errors in driving towards the wrong product tank.
Driver fails to recover the error	Upon reaching the storage area, the driver may realise the error from labels, safety signs etc. The driver is assumed to be trained in hazardous materials handling.
Operator fails to recover the error	Work site personnel will be present at the tank area to receive the tanker, check tank/tanker labels, check the transport documents carried by driver, check sample for pH and only then authorise the driver to unload the contents. The site operator will be trained and qualified to handle such tasks. He is therefore expected to recover the error.
Right product in wrong tank	This refers to acid tanker being driven and unloaded in to hypo tank or hypo tanker being driven and unloaded in to acid tank.
Wrong product delivered by supplier	This refers to wrong product being delivered at site by the supplier. The label on the tanker and the document carried by the driver may be different from the actual product in the tanker due to operator error at the supplier end.
Operator fails to check product sample	The site operator as per procedures is required to check the product by sampling. He is suitably trained and qualified for such tasks.
Wrong product in right tank	This refers to wrong product being unloaded into the right tank, ie if acid is expected to be received and unloaded, the tanker is driven to acid storage but the product contained in the tanker is different (it may be hypo, alkali or other product. It is assumed hypo here). The labels and documents show differently from the actual product in the tanker.

Figure I8c Fault Tree for Operator Error Leading to Mixing of Acid with Hypochlorite

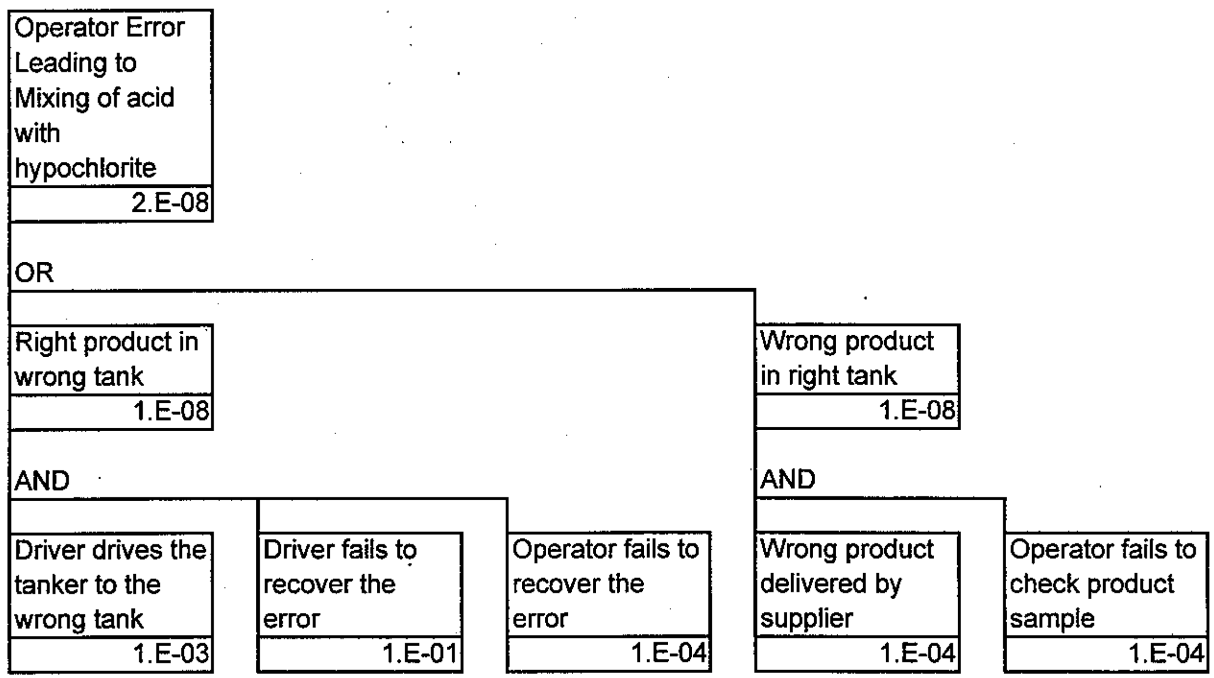


Table I8d ***Selected Generic Human Error Rate (based on Hunns and Daniels)***

Error Type	Type of Behaviour	Nominal HEP
1	Extraordinary errors of the type difficult to conceive how they occur: stress free, powerful cues initiating for success.	10^{-5}
2	Error in regularly performed commonplace simple tasks with minimum stress.	10^{-4}
3	Errors of commonplace such as operating the wrong button or reading the wrong display. More complex task, less time available, some cues necessary.	10^{-3}
4	Errors of omission where dependence is placed on situation cues and memory. Complex, unfamiliar task with little feedback and some distractions.	10^{-2}
5	Highly complex task, considerable stress, little time to perform it.	10^{-1}
6	Process involving creative thinking, unfamiliar complex operation where time is short, stress is high.	10^{-1} to 1

I9 CONSEQUENCE MODELS

I9.1 FIREBALL MODELS

The fireball models include empirical models for determining the diameter and duration of fireball. Empirical models for fireballs from explosives are given for high explosives [1].

For high explosives, the following are the relations:

$D = 3.5M^{1/3}$
$t = 0.3M^{1/3}$

where
D is diameter of fireball (m),
t is duration of fireball (seconds),
M is mass of high explosive (kg).

In order to model the fireball effects from fireworks, the model for high explosives is adopted but considering the TNT equivalent.

The TNT equivalent for fireworks is calculated from the following relation:

$$M_{TNT} = \frac{M_{FW} H_{FW}}{H_{TNT}}$$

where,

M_{TNT}	: Equivalent mass of TNT (kg)
M_{FW}	: Mass of fireworks (kg) - net explosive quantity
H_{TNT}	: Heat of combustion of TNT (KJ/kg)
H_{FW}	: Heat of combustion of fireworks (KJ/kg)

The heat of combustion of TNT is 15,132 kJ/kg. The composition of shell includes black powder for lift charge, flash powder for burst charge and star composition which can be assumed similar to black powder. A 5" shell will typically consist of 100g of burst charge, 150g of lift charge and 400g of star composition. The heat of combustion of flashpowder is 7534 kJ/kg while for blackpowder is 2762 kJ/kg. The equivalent heat of combustion is about 3500 kJ/kg.

From the above, the TNT mass equivalent is estimated as 925kg. The diameter and duration of the fireball are estimated as 34m and 2.9 seconds.

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1 Lees, F.P, Loss Prevention in Process Industries, 1996

Wharton and Merrifield conducted a series of experiments on a range of pyrotechnics with quantities up to 25kg and derived the following relationship for blackpowder :

$D = 3.1M^{0.279}$

Assuming that the above equation can be extrapolated to larger quantity of fireworks, this yields about 31m for a mass of 4000kg which is comparable with the value derived earlier.

The surface emissive power can be estimated as follows:

$$E = \frac{F_r Q_c}{A_f}$$

where,

F_r : Fraction of heat radiated
A_f : Surface area of fireball (m^2)
Q_c : Total heat release rate (kW)

The fraction of heat radiated is assumed as 0.4. The total heat release rate is estimated from heat of combustion as (4000kg x 3500 kJ/kg)/2.9s = 4.83×10^6 kW. The surface area of fireball of 34m diameter is $3629m^2$.

The surface emissive power estimated from the above is 532 kW/m2.

The surface emissive power can also be calculated as follows

$E = \sigma \varepsilon T^4$

where,
σ : Stefan-Boltzmannn Constant 5.67×10^{-11} (kW/m^2K^4)
ε : Emissivity (assumed as 1)
T : Temperature of fireball (K)

The temperature of the fireball from fireworks is considered to be less than 2000K. The emissive power estimated earlier as 532 kW/m^2 corresponds to a temperature of 1750K which is reasonable.

The thermal radiation intensity received by a target is given as

$I = E \times \tau \times F$

$$F = \frac{r^2}{l^2}$$

where,
F : view factor
τ : transmissivity

r : radius of the fireball (m)
l : distance of the target from the centre of the fireball (m).

Transmissivity is estimated as 0.75 for 70% humidity.
Surface emissive power is 532 kW/m^2

The probit equation given by Eisenberg [1]is used for estimation of fatalities due to thermal radiation effects. The probit equation is given below:

Eisenberg : $Y = -14.9 + 2.56 \ln L$

where, L is the thermal load = $tI^{4/3}$
t is the exposure time, seconds
I is the thermal radiation intensity, kW/m^2

The distance to 1% and 50% fatality are estimated based on the above equations. The probit values for 1% and 50% fatality are 2.67 and 5 respectively.

The probability of fatality within fireball diameter is assumed to be 100%.

I9.2 *EXPLOSION MODELS*

The characteristics of blast waves produced by explosions are generally described using scaling laws which assumes that the blast peak pressure at a given distance is proportional to the cube root of the mass of explosive. The models for predicting indoor and outdoor fatalities are further described below.

Model for Estimation of Indoor Fatalities

For predicting indoor fatalities (i.e. fatalities within buildings) due to accidental explosions, the model proposed by Gilbert, Lees and Scilly [i] has been used. The model applies to damage to low rise brick-built housing. It is considered pessimistic for application to high rise reinforced concrete structures which would be expected to be more resistant to the effects of blast. The model assigns varying probabilities of death (and injury) to varying levels of housing damage, as summarised in *Table I9.2a.*

1 Lees, F.P, The Assessment of Major Hazards: A Model for Fatal Injury from Burns , Trans IChemE Vol 72, Part B, 1994

Table I9.2a ***Model for Estimating Fatalities due to Explosions in Built-Up Areas***

Housing Damage Category	Description	Fatality Probability
A	Houses completely demolished, i.e. with over 75% of external brickwork demolished.	0.62
B	Houses so badly damaged that they are beyond repair and must demolished when opportunity arises. Property is included in this category if 50-75% of external brickwork is destroyed or in the case of less severe destruction the remaining walls have gaping cracks rendering them unsafe.	0.086
Cb	Houses which are rendered uninhabitable by serious damage, and need repairs so extensive that they must be postponed until after the war. Examples of damage resulting from such conditions include partial or total collapse of roof structures, partial demolition of one or two external walls up to 25% of the whole, and severe damage to the load bearing partitions necessitating demolition and replacement.	0.009

The distance to particular levels of housing damage is calculated according to the following equation [1]

$$R = kM^{1/3}/[1+(3175/M)^2]^{1/6}$$

where,

k = 4.8 (Cat A), 7.1 (Cat B) and 12.4 (Cat Cb)
M = mass of explosive (kg)
R = distance to specified level of housing damage (m)

The above equation is derived for high explosives using data obtained from wartime damage and therefore the TNT equivalent is used for modelling fireworks. The TNT equivalent is derived from the ratio of energy of explosion. The energy of explosion for TNT is 4850 kJ/kg. The energy of explosion for fireworks is not available and is therefore assumed that the ratio of energy of explosion is similar to ratio of heat of combustion.

$$M_{TNT} = \frac{M_{FW} H_{FW}}{H_{TNT}}$$

where,

M_{TNT} : Mass Equivalent of TNT (kg)
M_{FW} : Mass of fireworks (kg) - net explosive quantity
H_{TNT} : Heat of combustion of TNT (KJ/kg)
H_{FW} : Heat of combustion of fireworks (KJ/kg)

The heat of combustion for TNT is 15,132 kJ/kg and for fireworks 3500 kJ/kg. The TNT equivalent is estimated as 925 kg.

1 F.P Lees, Loss Prevention in Process Industries, 1996

Probits for Outdoor Fatalities

In general, the human body is much more resistant to blast effects than fixed structures, although eardrum and sinus injuries can occur at overpressures as low as 0.2 bar. Eardrum rupture is not usually life threatening. Blast injuries to the chest occur at about 0.65 bar. An overpressure level of 1 bar could be expected to cause life threatening chest injuries (lung haemorrhage) to persons outdoors.

The other modes of injury due to explosion to persons outdoors are body translation, fragments and thermal effects. The thermal effects have already been described. Fragments of concrete or whole bricks from store construction can travel significant distances but modelling of these effects is complex. Safety distances are evolved based on accident data and trials involving blast fragments.

The probit equation[1] for fatality from lung haemorrhage is given as

$Y = -77.1 + 6.91 \ln (P^{o})$,

where P^{o} is the peak overpressure generated by the blast in Pascal units.

The peak overpressure corresponding to 1% fatality is 103170 Pa or about 1 bar.

The probit equation for fatalities due to bodily translation is given by,

$Y = -2.14 + 2.54\ln(V)$, where

V is the maximum velocity imparted to the body (m/s)

I9.3 ESTIMATION OF FATALITIES

I9.3.1 *Fatalities due to Fireworks Transport*

Fireball Effects on Road Users

The number of vehicles within the hazard range for fireball or explosion is estimated as follows :

$$\text{No. of vehicles within hazard range} = \frac{N \times R}{V \times 1000}$$

where,

N : Number of vehicles per hour (assumed as 500)

R : Length of affected road. This is equal to the estimated hazard range (m) plus adjustment for effective stopping distance assumed as 20m minus length of explosive vehicle assumed 10m.

V : Average Speed of vehicles (assumed as 50 km/h)

The equivalent number of fatalities is estimated assuming 3 persons per vehicle. To account for the potential for involvement of larger vehicles in addition to cars, the equivalent fatality is expressed as probability of different level of fatality as given in following tables.

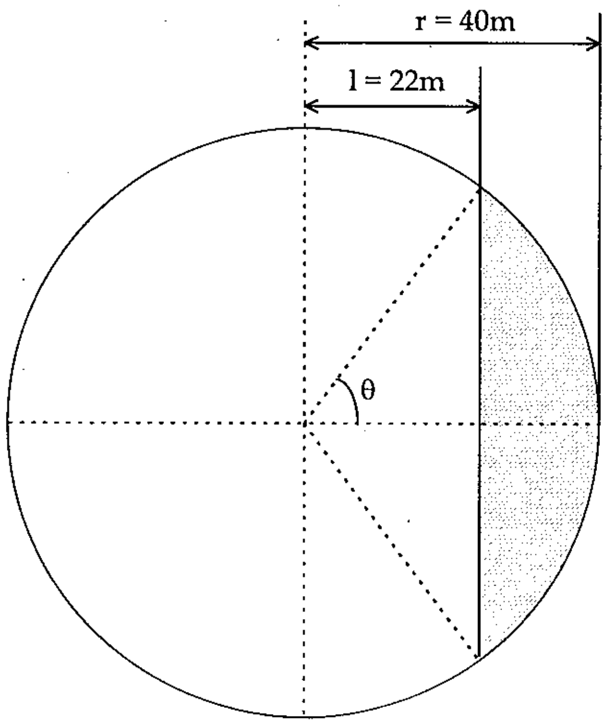
Table I9.3a ***Probability and Number of Fatalities of Road Users due to Fireball Effects***

Hazard	Hazard range (m)	Modified hazard range (m)	No of vehicles	Equivalent fatality	Probability of given number of fatalities			
					1	2	3	6
Fireball								
10% fatality*	80	90	0.9	0.14				
100% fatality	34	44	0.44	1.32				
Overall-fireball				1.5	0.2	0.5	0.1	0

* : 10% fatality probability considered for the region between fireball diameter (100% fatality) and 1% fatality contour. The equivalent fatality is derived based on vehicles within the region between fireball diameter and 1% fatality contour (ie, 0.9-0.44).

Fireball Effects on Hotel Residents

The actual layout of hotel building within the development and its proximity to the road is not known. For the purpose of this EIA study, it is assumed that the hotel building is about 22m from the road. Although the average population density for the hotel development site is derived as 2.6 persons per $100m^2$ (see *Table 10.3b* in main Report), it is likely that population will be concentrated in specific areas within the site. Accordingly, a density of 1 person per $10m^2$ is assumed based on density for built-up areas within the city. The affected area is calculated as follows:



Area = $\theta r^2 - l r \sin\theta$, where θ is in radians.

It is further assumed that about 10% of the residents will be outdoors and 90% indoors. The probability of fatality for indoors is 10% of outdoors.

Table I9.3b ***Probability and Number of Fatalities of Hotel Residents due to Fireball Effects***

Hazard	Hazard range (m)	Affected area (m^2)	No of persons	Equivalent fatality	Probability of given number of fatalities			
					1	2	3	6
Fireball								
10% fatality*	40	850	85	1.7	0.2	0.6	0.1	0
100% fatality	No effect							
Overall-fireball				1.7	0.2	0.6	0.1	0

* : 10% outdoor fatality probability considered for the region between fireball diameter (100% fatality) and 1% fatality contour. However, equivalent fatality probability considering indoor-outdoor distribution is 0.02.

Explosion Effects on Hotel Residents

The number of hotel residents affected by explosion incidents on road is calculated as above.

Table I9.3c ***Probability and Number of Fatalities of Hotel Residents due to Explosion Effects***

Hazard	Hazard range (m)	Affected area (m^2)	No of persons affected	No. of fatalities
Explosion				
2.8% fatality*	79	5099	510	14
23% fatality*	45	1014	101	23
62% fatality	31	269	27	17
Overall-explosion				54

* : 2.8% fatality probability considered for the region defined by R(Cb) and R(b). 23% fatality probability for the region defined by R(B) and R(A). See *Table 10.7b* in Main Report.

I9.3.2 *Fatalities due to Fireworks Shell Bursting/Impact Injury Effects on Visitors/Road Users*

Shell Burst Effects on Visitors within Theme Park

The number of fatalities due to shell burst will depend on the size of shell and the crowd density. Not all viewing areas inside the Park will be densely packed. The probability of different levels of fatality is assumed as given in *Table I9.3d*.

Table I9.3d ***Probability and Number of Fatalities due to Shell Burst Effects on Visitors within Theme Park***

Shell size	Proportion of all shells	Probability of given number of fatalities due to shell burst in crowd					Equivalent fatality
		1	2	4	6	8	
3"	0.5	0.3	0.5	0.2	0	0	2.1
4"	0.3	0.2	0.3	0.3	0.2	0	3.2
5"	0.2	0.1	0.2	0.4	0.2	0.1	4.1

Shell Impact Injury Effects on Visitors within Theme Park

In the event a shell lands on crowd and hits a person but does not initiate, the impact velocity of the shell (which is a few tens of metres per second) may be high enough to cause a fatality. However, a fatality incident is expected only when a shell hits the head directly. The probability of a direct hit can be estimated approximately as maximum 10% for a crowd density of $2/m^2$ (based on 'head area' as a proportion of the standing area of crowd). However, considering areas with lower crowd density, an average value of 5% is assumed. The probability of fatality upon being hit is assumed as 10%, 30% and 50% for shell sizes, 3", 4" and 5" respectively.

Shell Burst Effects on Road Users

A shell could land on passing vehicles on road and burst on impact causing fatalities (where the shell does not burst on impacting a passing vehicle, no fatality is assumed to be caused due to protection provided by the vehicle). A shell may also land on road and may burst when overrun by vehicles.

The probability of a shell landing on a passing vehicle is estimated as 0.1 based on equation given above. The length of affected road is equal to length of vehicle (assumed 5m) plus adjustment for additional impact distance of 5m.

In the event of a shell overrun by a vehicle, the consequences are assumed to be greater due to the impact of a shell bursting underneath a vehicle as compared to a shell bursting on vehicle body upon landing.

The following distribution of fatalities is assumed.

Table I9.3e ***Probability and Number of Fatalities due to Shell Burst Effects on Road Users***

Shell size	Proportion of all shells	Probability of given number of fatalities due to shell burst effects				Equivalent fatality	
		1	2	3	6	A	B
Shell bursts upon landing on a vehicle							
3 "	0.5	0.05	0	0	0	0.05	0.5
4"	0.3	0.07	0	0	0	0.07	0.7
5"	0.2	0.1	0	0	0	0.1	0.1
Shell bursts when overrun by vehicle							
3 "	0.5	0.8	0.2	0	0	-	1
4"	0.3	0.6	0.3	0.1	0	-	1.5
5"	0.2	0.4	0.5	0.2	0	-	2

Note : 'A' represents equivalent fatality considering vehicle presence probability. 'B' represents equivalent fatality given vehicle presence. Vehicle presence probability is assumed 1 for the second case.

It is assumed that there will be no spectators/pedestrians standing on the road watching the fireworks display from the Resort Road.

I9.3.3 Fatalities due to Chlorine Release

The LD3 distance due to chlorine release will extend over the Resort road. The number of fatalities of road users is estimated based on the equation above for number of vehicles and assuming crosswind distance of 200m. The fatality probability is assumed as 12% (geometric mean of 3% and 50% fatality at source).

The equivalent fatality for road users is estimated as 1.

The incident data provided by Disney and the incident data for the UK show a large number of minor injuries causing eye irritation due to smoke or ash. A brief discussion of the hazards due to debris and the conditions under which this may occur is included in the following paragraph.

Minor injuries, for instance ash in eyes, are generally caused by wind drift of both lit and unlit debris once the firework has functioned. The distance that debris travels is dependant on:

1) The position of firework functioning horizontally in relation to the audience
2) The height at which the firework functions
3) The wind speed
4) The time taken for debris to fall to earth

The risk to the audience is also dependent on the wind direction.

From the above it is clear that the fireworks giving the greatest risk from debris are shells. Low level items are unlikely to drop debris on remote audiences.

Analysis of wind strength and direction at Lantau over a 12 month period during the time period 20:00 to 22:00 (estimated medium level display time is 21:30) gives the following results:

Table I10a ***Wind direction/Strength at Lantau (wind speed in m/s)***

Direction	Wind								Total	
	<1	1-3	3-5	5-7	7-9	9-12	12-15	>15		
N	1	10	36	31	13	9	1	0	101	14%
NE	0	4	18	9	3	0	0	1	35	5%
E	1	12	38	52	50	26	2	1	182	26%
SE	0	26	43	56	39	12	0	1	177	25%
S	0	26	39	12	4	2	0	0	83	12%
SW	0	15	31	20	14	5	0	0	85	12%
W	0	13	9	9	2	2	0	0	35	5%
NW	2	3	2	1	0	0	1	0	9	1%
Total	4	109	216	190	125	56	4	3	707	
	1%	15%	31%	27%	18%	8%	1%	0%		

Estimated fall out distances for debris dependent on shell size are given below:

Table I10b *Debris distance for Shells*

Calibre	Approx .Burst Height (m)	Approx Burst Dia (m)	Wind 1m/s	3m/s	5m/s	7m/s	9m/s	12m/s
3"	67	11	11	19	27	38	53	68
4"	107	17	15	25	37	52	72	92
5"	137	21	19	31	45	63	87	112

Source: UK CBI/BTEC Guidelines

The above table underestimates the debris distance travelled by extremely light fragments.

The above data suggests that under normal wind conditions at Lantau the debris will fall to earth before it reaches the audience, regardless of wind direction. Only in very high winds should moderation or cancellation of the display be necessary.

I11 PLL CALCULATION DETAILS

The details of FN pairs and PLL calculations are provided in the following tables.

Table I11a *FN Pairs*

Number of Fatalities (N)	Frequencies of N or more Fatalities						
	a1	a2	b1	b2 & b3	c	Public off-site	Overall
1	6.91e-7	3.41e-6	5.42e-6	1.30e-6	1.5e-6	2.36e-6	3.05e-6
2	2.43e-7	1.19e-6	4.16e-6	1.04e-6	-	7.89e-7	1.03e-6
3	1.23e-7	2.31e-7	6.30e-7	2.60e-7	-	1.12e-6	2.35e-7
4	1.23e-7	-	-	1.30e-7	-	1.30e-7	1.36e-7
6	3.79e-8	-	-	1.30e-7	-	1.30e-7	5.09e-8
8	6.32e-8	-	-	1.30e-7	-	1.30e-7	1.93e-8
54	-	-	-	1.30e-7	-	1.30e-7	1.30e-8

For a1, a2, b1, b2,b3 and c, refer to *Table 10.8a* in main Report.

Table I11b PLL Calculation Details

		Outcome frequency corresponding to given number of fatalities								
		1	*2*	*3*	*4*	*6*	*8*	*54*	Reference	PLL
5" shell										
	Visitors affected by shell burst on impact	6.3E-09	1.3E-08	-	2.5E-08	1.3E-08	6.3E-09	-	Table 8b, Tabl	2.59E-07
	Visitors affected by shell impact on head	1.6E-07	-	-	-	-	-	-	Table 8b, Tabl	1.56E-07
	Vehicle passengers affected by shell burst on impact	1.3E-09	-	-	-	-	-	-	Table 8b, Tabl	1.33E-09
	Vehicle passengers affected by shell burst when overrun	2.6E-08	3.3E-08	1.3E-08	-	-	-	-	Table 8b, Tabl	1.32E-07
4" shell										
	Visitors affected by shell burst on impact	1.9E-08	2.8E-08	-	2.8E-08	1.9E-08	-	-	Table 8b, Tabl	3.03E-07
	Visitors affected by shell impact on head	1.4E-07	-	-	-	-	-	-	Table 8b, Tabl	1.41E-07
	Vehicle passengers affected by shell burst on impact	1.4E-09	-	-	-	-	-	-	Table 8b, Tabl	1.40E-09
	Vehicle passengers affected by shell burst when overrun	5.9E-08	3.0E-08	9.9E-09	-	-	-	-	Table 8b, Tabl	1.49E-07
3" shell										
	Visitors affected by shell burst on impact	4.7E-08	7.9E-08	-	3.2E-08	-	-	-	Table 8b, Tabl	3.32E-07
	Visitors affected by shell impact on head	7.8E-08	-	-	-	-	-	-	Table 8b, Tabl	7.82E-08
	Vehicle passengers affected by shell burst on impact	1.7E-09	-	-	-	-	-	-	Table 8b, Tabl	1.67E-09
	Vehicle passengers affected by shell burst when overrun	1.3E-07	3.3E-08	-	-	-	-	-	Table 8b, Tabl	1.98E-07
a1)	Fireworks shell affecting visitors									
	3" shell	1.3E-07	7.9E-08	-	3.2E-08	-	-	-	Table I9.3d	4.10E-07
	4" shell	1.6E-07	2.8E-08	-	2.8E-08	1.9E-08	-	-	Table I9.3d	4.44E-07
	5" shell	1.6E-07	1.3E-08	-	2.5E-08	1.3E-08	6.3E-09	-	Table I9.3d	4.16E-07
a2)	Fireworks shell affecting road users									
	3" shell	1.3E-07	3.3E-08	-	-	-	-	-	Table I9.3e	2.00E-07
	4" shell	6.1E-08	3.0E-08	9.9E-09	-	-	-	-	Table I9.3e	1.50E-07
	5" shell	2.8E-08	3.3E-08	1.3E-08	-	-	-	-	Table I9.3e	1.33E-07
b1)	Firework transport affecting road users	1.3E-07	3.5E-07	6.3E-08	-	-	-	-	Table I9.3a	1.02E-06
b2)	Fire events during fireworks transport affecting hotel occupants	2.6E-08	7.8E-08	1.3E-08	-	-	-	-	Table I9.3b	2.21E-07
b3)	Explosion events during fireworks transport affecting hotel occupants	-	-	-	-	-	-	1.3E-08	Table I9.3c	7.02E-07
c)	Chlorine release due to accidental mixing of acid and hypochlorite affecting road users	1.5E-06	-	-	-	-	-	-	Section I9.3.3	1.50E-06

PLL for visitors due to fireworks shell	*1.27E-06*
PLL for public due to fireworks shell	*4.83E-07*
PLL for public due to fireworks transport	*1.94E-06*
PLL for public due to chlorine release	*1.50E-06*
Total PLL	5.20E-06