10 HAZARD ASSESSMENT OF DANGEROUS GOODS (FIREWORKS, SODIUM HYPOCHLORITE) INCIDENTS RESULTING IN LOSS OF LIFE

10.1 INTRODUCTION

10.1.1 This section of the report presents a summary of the analysis and findings of the study on 'Hazard to Life' due to storage, use, transport, handling and processing of dangerous goods (fireworks and sodium hypochlorite) during the operational phase of the Theme Park. Additional supporting information is included in *Annex I*.

10.2 LEGISLATION, STANDARDS, GUIDELINES AND CRITERIA

10.2.1 The following legislation, standards, guidelines and criteria are relevant to the control and evaluation of hazards (including the transport, storage and discharge of fireworks and sodium hypochlorite).

- *Dangerous Goods Ordinance* (Cap. 295);
- *Dangerous Goods (Application and Exemption) Regulations;*
- *NFPA 1123 Code for Fireworks Display;*
- *NFPA 1126 Standard for the Use of Pyrotechnics before a Proximate Audience*;
- *Environmental Impact Assessment Ordinance (Cap. 499.S16)*. Technical Memorandum on Environmental Impact Assessment Process (EIAO TM);

DANGEROUS GOODS ORDINANCE

Classification of Fireworks

10.2.2 Fireworks are classified as dangerous goods under *the Dangerous Goods Ordinance* and its subsidiary regulation, *Dangerous Goods (Application and Exemption) Regulations*. Under the DG Regulations, manufactured fireworks are classified as explosives, i.e., Category 1, Class 7 (fireworks), Division 2 (manufactured fireworks).

10.2.3 The Hong Kong DG Ordinance and its subsidiary regulations are currently being amended to align with the international rules such as the United Nations (UN) Recommendations and the International Maritime Dangerous Goods (IMDG) Code.

10.2.4 The UN Classifications and UN Numbers for all items proposed to be used at the Theme Park are given in *Table 10.2a*. The explanation for the hazard division and compatibility group is included in *Section 1* of *Annex I*. Definitions for explosives, fireworks, pyrotechnics and other terms are also given in *Section 1* in *Annex I*.

Table 10.2a - UN Numbers for Fireworks

Shipping Name	UN Number	UN Hazard Division and Compatibility Group
Fireworks	0335	1.3G
Fireworks	0336	1.4G
Articles Pyrotechnic	0431	1.4G
Articles Pyrotechnic	0432	1.4S
Igniters	0454	1.4S

Fireworks Transport to Site

10.2.5 The conveyance of fireworks by public roads in HKSAR is governed by the Dangerous Goods Regulations. Under Regulation 4, a removal permit is required for transport on public roads. Also, the road vehicle carrying fireworks should be of an approved type. The specifications for vehicles laid down by the Commissioner of Mines will be adopted by the Theme Park operator.

Fireworks Storage

10.2.6 Storage of fireworks and pyrotechnics is governed by the Dangerous Goods (General) Regulations. Under the regulations, a license is required for storage. Also, manufactured fireworks exceeding 200kg are required to be stored in a Mode A store. The general requirements for a Mode A store construction are specified in regulation 11 while specific requirements may be set by the Controlling Authority, the Commissioner of Mines. The security and safety requirements of Mode A stores are outlined in Regulations 13 to 27.

10.2.7 The requirements for a Mode A store are as follows:

- The store shall consist of a single storey detached structure made of concrete;
- No ferrous metal used in the construction or fittings shall be exposed such that it can present a spark hazard;
- The store shall be provided with a lightning conductor;
- The store shall be securely locked;
- A security fence (chain link fencing 2.5m high) surrounding the store shall be set back at least 6m from the store. The gate in the security fence shall also be locked;
- The trucks for delivery shall be driven up to the gate of the security fence;
- The store shall be separated from public areas by specified distances (see discussion below);
- Fire fighting equipment consisting of four fire extinguishers, four buckets of sand and four buckets of water shall be positioned within the area between the security fence and the store. Additional fire service installations may be imposed by the Fire Services Department upon receipt of building plans for approval.

10.2.8 The proposed store for fireworks and pyrotechnics inside each park will be constructed in accordance with the requirements for a Mode A store as specified in the regulations and by the Controlling Authority.

10.2.9 The minimum separation distances from storage areas to public roads and buildings are governed by the quantity-distance relations. The Hong Kong requirements are based on the UK requirements, particularly in respect of distance to offsite facilities. See *Section 3.5* in *Annex I* for details on Offsite Safety Distances for different hazard classes of explosives and for different quantities of explosives.

10.2.10 For the proposed store of 4 tonnes NEQ of mixed 1.3 and 1.4 explosives the required distances are:

- 50m to roads and other low occupancy sites;
- 101m to houses and other high occupancy sites.

10.2.11 Both of these distances are able to be accommodated for the proposed location of the store within the back of house area in each park.

Fireworks Discharge

10.2.12 The discharge of fireworks and pyrotechnics are governed by the Dangerous Goods (General) Regulations. Regulation 59 requires a license to be obtained from the Secretary of Home Affairs (SHA) in the case of discharge of fireworks from land. The application for fireworks discharge is vetted by the Fireworks Vetting Committee (FVC) and approved by the Executive Council before a permit is issued by SHA.

10.2.13 The applicant is required to provide details on the fireworks display including location, type of fireworks, number of fireworks, duration, classification and packaging of fireworks, technical specifications from the manufacturer such as principal and side effects, projected height, fallout radius, fragment hazard, chemical composition, weight etc.

10.2.14 Based on the above, the Commissioner of Mines provides technical advice to SHA and FVC on the safety requirements in the case of discharge from land. The safety requirements are based on NFPA 1123 Code for Fireworks Display. The Commissioner of Mines may also administer a test and interview to satisfy that the pyrotechnician responsible for fireworks discharge has adequate qualifications and experience.

10.2.15 The license for discharge of pyrotechnics is issued by the Commissioner of the Television and Entertainment Licensing Authority (TELA). The licensing of storage and transport of pyrotechnics however, is currently under the purview of the Commissioner of Mines. The proposed Entertainment Special Effects Bill seeks to bring under the scope of TELA all aspects relating to pyrotechnics storage, conveyance, removal and discharge. The proposed bill also seeks to introduce a license for the special effects (pyrotechnics) operators.

10.2.16 The safety requirements for fireworks display are laid down in the following NFPA Codes:

- NFPA 1123 : Code for Fireworks Display and
- NFPA 1126 : Standard for the Use of Pyrotechnics before a Proximate Audience.

10.2.17 The former will apply to medium-level and low-level shows while the latter will apply to stage shows. The requirements by the Commissioner of Mines, TELA and the Fire Services Department are also broadly in conformance with the requirements in the NFPA Code. The Theme Park operator will adopt these requirements.

10.2.18 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. For mid-level fireworks display consisting of up to 5” diameter shells, the minimum separation distance to spectator viewing areas and other public areas is 107m. The minimum separation distance from the firing site to the dangerous goods stores is twice the minimum separation distance to spectator areas (i.e. 2 x 107m = 214m).

10.2.19 Further details on safety distances for outdoor and stage displays are given in *Section 3.6* in *Annex I*. Other safety requirements for conducting display are described in *Section 3.2* *to 3.4* in *Annex I*. The quality control adopted by the Theme Park operator is described in *Section 3.1* in *Annex I*.

Classification of Hypochlorite

10.2.20 Sodium hypochlorite is currently classified as 'poison', i.e. Category 4 in the Dangerous Goods Regulations. However, under the UN classification which will be adopted soon, sodium hypochlorite is classified as corrosive, i.e. UN Class 8. The UN number is 1791. The packing group (PG) is II or III depending on the concentration. Concentration of more than 5% but less than 16% available chlorine is PG III while concentration of 16% and above is PG II (substances are assigned to Packing Group according to the degree of danger they present. PG I, II and III represent high, medium and low danger respectively).

10.2.21 Under the existing Dangerous Goods Regulations, storage of hypochlorite in quantity exceeding 250 litres requires a license. The licensing authority for corrosives and toxics is Fire Services Department. The exempted quantity for hypochlorite solution under the proposed amendments is 250kg.

10.2.22 Under the proposed amendments to the DG Regulations, bulk tanks for storage of corrosives and toxics will require to be certified and tested by competent persons.

EIAO TM

10.2.23 The requirements for hazard assessment of projects involving the storage, use or transport of dangerous goods are specified in Section 12 and *Annex 22* of the EIAO-TM.

10.2.24 Additionally, *Annex 4* of the EIAO TM specifies the individual risk guidelines and societal risk guidelines.

Individual Risk

10.2.25 Individual risk is defined as the frequency of fatality per year to a specific individual due to the realisation of specified hazards, with account taken of temporal factors.

10.2.26 The maximum level of off site individual risk should not exceed 1 in 100,000 per year, i.e. 1×10^{-5} per year.

Societal Risk

10.2.27 Societal risk is defined as the risk to a group of people due to all hazards arising from a hazardous operation. The simplest measure of societal risk is the Rate of Death or Potential Loss of Life (PLL), which is the predicted equivalent fatalities per year.

10.2.28 Societal risk is also expressed in the form of an F-N curve, which represents the cumulative frequency (F) of all event outcomes leading to N or more fatalities. This representation of societal risk highlights the potential for accidents involving large numbers of fatalities.

10.2.29 The societal risk guidelines expressed in the form of FN curve is shown in later section. There are three regions identified :

- Unacceptable region;
- ALARP region where risk is tolerable providing it has been reduced to a level As Low As Reasonably Practicable;
- Acceptable region where risk is broadly acceptable.

Application of Criteria

10.2.30 The risk guidelines specified in the EIAO TM apply only to risk of fatality due to storage, use or transport of dangerous goods. Injuries are not considered in the assessment and similarly, hazards due to operations within the Theme Park other than those involving dangerous goods are also not considered.

10.2.31 The risk guidelines have been generally applied for only public off site of a hazardous installation. However, in the context of this study, the risk guidelines are applied to the public inside and outside of the Theme Park which include visitors to the Theme Park, guests/staff in the hotel development outside the Theme Park and general public in the vicinity of the Theme Park such as public roads. The risks to staff working inside the Theme Park are not evaluated.

10.3 STUDY APPROACH AND METHODOLOGY

10.3.1 The EIA Study approach and assessment methodology for the Hazard to Life study includes the following key elements:

- Identification of all hazardous scenarios associated with the storage, use, transport, handling and processing of dangerous goods (fireworks and sodium hypochlorite) during Theme Park operation stages. Hazard identification has included a review of past incident data for fireworks and sodium hypochlorite;

- Preparation of a Quantitative Risk Assessment (QRA) to express population risks in both individual and societal terms;

- The estimated individual and societal risk levels have then be compared with the Criteria for Evaluating Hazard to Life stipulated in *Annex 4* of the EIAO TM;

- Where necessary, practicable and cost-effective risk mitigation measures have been identified and assessed by means of cost-benefit analysis; and

- The final stage of the Hazard to Life study has been to determine whether the Theme Park and its associated facilities pose acceptable levels of risk to the public off-site and the visiting population (on-site) after mitigation.

10.3.2 Additional details on the specific assessment methodologies and criteria that have been utilised are provided in subsequent sections.

10.4 DESCRIPTION ON THEME PARK DEVELOPMENT

10.4.1 Specific details of the Theme Park and associated developments that are relevant to the Hazard to Life assessment are provided below; additional supporting details of the Project are provided in *Section 2* of this report.

10.4.2 The key elements of the Project are:

- Development of the Theme Park, Retail, Dining and Entertainment (RD&E) facilities and Hotels. A water recreation centre to the north is also proposed as part of the Theme Park development; and
- Transportation Infrastructure including Chok Ko Wan Link Road, Road P2, Resort Road, a central pedestrian walkway located between the two Theme Parks, Penny's Bay Rail Link, two public parking areas at Penny's Bay, a Public Transport Interchange, two ferry piers on the southern waterfront and a separate service quay along the seawall.

10.4.3 *Figure 10.3a* shows the conceptual layout for the Theme Park and associated developments. Indicative locations for the proposed fireworks and sodium hypochlorite stores and fireworks display site (for mid-level shows) are also shown in *Figure 10.3a*.

10.4.4 The area of each of the Theme Parks (Phase I and II) is about 63 hectares (i.e., 0.63 km^2). The dimensions of each Park are approximately 900m by 700m. The back of house area where visitors will not be permitted is estimated to cover about 25% (i.e., 15 ha or 0.15 km^2) while the RD&E will cover about 13% (i.e., 8 ha or 0.08 km^2) of the area. The Theme Park attractions open to visitors will cover the remaining 62% of the area (i.e., 40 ha or 0.4 km^2). The majority of buildings and structures within the Theme Park will be low to medium rise; the maximum height of structures will be limited to 100m. The Theme park will be separated from adjoining developments by landscaped berms, 9 m high and 38 m wide.

10.4.5 The Theme park will remain open from 0800 to 2400 hours and the RD&E facilities will be open from 0900 to 0200 hours.

10.4.6 The hotel development will consist of 5 or more hotels with a capacity of up to 7,000 rooms, spread over an area of 53 ha (i.e. 0.53 km^2). Landscaped berms, 5 m high and 22 m wide will separate the hotels from each other to maintain independent themes for each hotel. Most hotels will be between 5 and 7 storeys and will not exceed 40m height.

10.4.7 Based on the indicative locations shown in *Figure 10.3a*, the available distance between the fireworks store and the hotel development is more than 600m and between the fireworks store and the transport infrastructure to the north is more than 100m. Similar distances are available from the sodium hypochlorite store. The distance from the two stores to the Resort Road will be minimum 50m (see hazard distances in *Section 10.8* and recommendation on optimisation study on separation distances in *Section 10.11*).

10.4.8 The distance from the fireworks display site (for mid-level shows) to the hotel development and similarly to the transport infrastructure facilities to the north is more than 300m. The distance from the fireworks display site to the Resort Road will be minimum 107m (see minimum separation distances in *Section 10.2.10*, hazard distances in *Section 10.8*).

POPULATION IN THE THEME PARK AND ASSOCIATED DEVELOPMENTS

10.4.9 *Table 10.4a* provides a summary of anticipated annual attendance at the Theme Park, the associated Retail, Dining and Entertainment (RD&E) facilities and the associated hotel development.

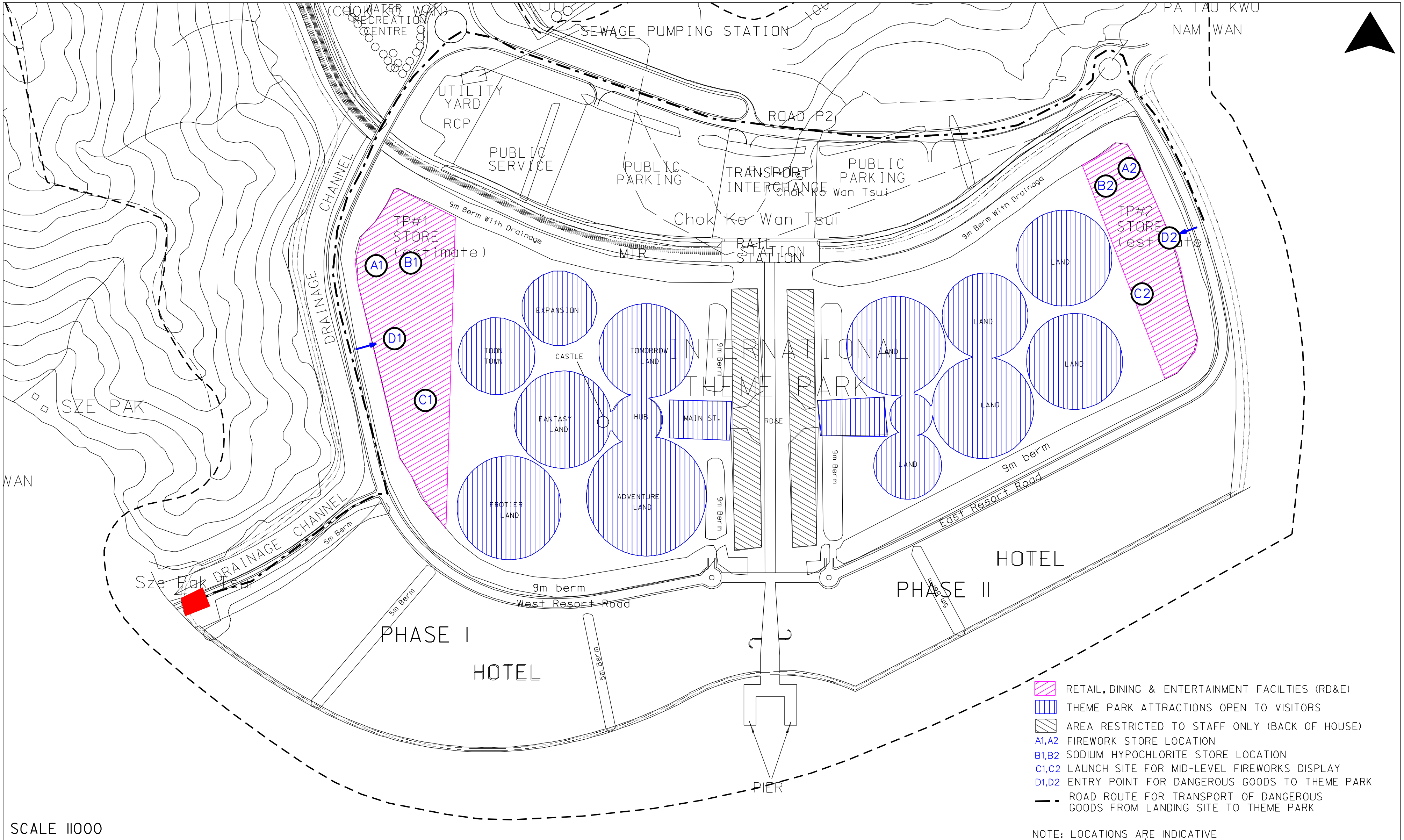

FIGURE 10.3a

CONCEPTUAL SITE LAYOUT FOR THEME PARK AND ASSOCIATED DEVELOPMENTS

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DATE: 02/2000

Environmental Resources Management

ERM

10.4.10 *Table 10.4b* provides the Reference Day attendance (i.e. maximum peak daily attendance) considered in this hazard assessment study and also approximate estimates of the percentage of the Reference Day visitor population (based on the operating experience of the Theme park Operator) for five different time periods.

10.4.11 The population in the hotel development is estimated assuming three guests and one staff per room.

Table 10.4a - Details on Theme Park Development

	Phase I- Opening	Phase I- Build Out	Phase II- Build Out
Estimated completion date	2005	2014	2024
Theme Park annual attendance	7.5 million	10 million	20 million
Theme Park average daily attendance	20,550	27,400	54,800
RD&E annual attendance	6.6 million	10.1 million	17.1 million
Hotel rooms	1400	3100	7000
Note : All values cumulative. Phase II values include Phase I and II			

10.4.12 The hazard assessment presented in this EIA Study is based on visitor data for Phase II - Build Out (see *Section 2*). The anticipated Theme Park attendance of 20 million is split equally between the two elements, Theme Park Phase I and Phase II.

10.4.13 Since RD&E and transport links are being developed primarily to serve the Theme Park visitors, only the number of visitors anticipated for Theme Park attendance are therefore considered to be present either within the Theme Park or outside in the RD&E or the transport facilities at any time.

10.4.14 Based on the areas for each development and the total population, average population densities have been estimated and presented in *Table 10.4b*.

10.4.15 In addition to the above, traffic population on Resort Road, which is the road closest to the Theme Park and traffic population on Road P2 through which fireworks will be transported are also considered in the hazard assessment. Traffic is assumed to be present on these roads at all times. Traffic projections for year 2016 available only for Road P2 near the Theme Park estimate a peak traffic of about 1400 vehicles per hour. The traffic during the night time is assumed as 500 vehicles per hour.

Table 10.4b - Population Distribution Throughout the Day

Facility	Reference Day Visitor Population	0800 to 1200 hrs	1200 to 2000 hrs	2000 to 2400 hrs	0000 to 0200 hrs	0200 to 0800 hrs
		4 hrs (16.7%)	8 hrs (33.3%)	4 hrs (16.7%)	2 hrs (8.3%)	7 hrs (25%)
Theme Park, Phase I						
Theme Park						
No. of visitors	42,000	16,800 (40%)	33,600 (80%)	21,000 (50%)	0	0
Avg. density	per 100 m^2	4.2	8.4	5.3	0	0
RD&E						
No. of visitors	35,100	1755 (5%)	2,808 (8%)	5,616 (16%)	1,404 (4%)	0
Avg. density	per $100m^2$	2.2	3.5	7	1.8	0
Hotel						
No. of persons	14,000	7,000 (50%)	5,600 (40%)	7,000 (50%)	12,600 (90%)	14,000 (100%)
Avg. density	per $100m^2$	1.3	1.1	1.3	2.4	2.6

Note :

a) The average (avg.) population density values presented in the table are based on total area cover including buildings and structures. However, during fireworks display when visitors would congregate in open areas such as service roads, pedestrian ways, and other open areas within the Park, typical crowd density of 2 persons/m^2 is assumed.

b) The values for Theme Park, Phase II are same as for Theme Park, Phase I given above.

SURROUNDING LAND-USE

10.4.16 There are no other developments adjoining the Theme Park development other than the future development proposed on the area to the east of Phase II Theme Park which may include either an extension to the Theme Park or other tourism related development.

10.4.17 The nearest existing residential developments are located over 2km from the centre of the Project site in Peng Chau Island and in Discovery Bay on Lantau Island. The proposed residential development at Tsing Chau Tsai to the north-east of Theme Park, Phase II will also be over 2km away.

FIREWORKS TRANSPORT & STORAGE

10.4.18 The proposed Theme Park will have fireworks displays and shows incorporating fireworks or pyrotechnics. These are part of attractions similar to rides or parades found in existing world class Theme Parks in Florida, California, Paris and Tokyo. Fireworks displays will require the storage of fireworks on site and transport of fireworks to site.

Fireworks/Pyrotechnics Transport to Site

10.4.19 Fireworks/pyrotechnics will be delivered by cargo ship from its point of origin to the Western Dangerous Goods Anchorage in Hong Kong. At the anchorage, the goods will be transferred from the cargo ship to a vessel approved by the Marine Department. The vessel would ferry the cargo container of fireworks to a landing site (vertical sea wall) located in the south-west corner of the Project site (see *Figure 10.3a*). At the landing site, the fireworks would be transferred from the container to a licensed road vehicle or the container would be transferred to a licensed trailer chassis and then trucked to the back of house area of either Theme Park. The land route will be along the proposed public roads Resort Road and Road P2 shown on *Figure 10.3a*. The distance from the landing site to the Theme Park Phase I and II is about 0.9 km and 3.7 km respectively.

10.4.20 It is anticipated that there will be approximately 4 deliveries of fireworks and pyrotechnics (each of NEQ maximum 4 tonnes) to the landing site per month or 48 deliveries per year when both Theme Park phases become operational.

10.4.21 The proposed landing site will be dedicated for goods handling including dangerous goods handling and will be located away from the public ferry piers. A separation distance of 75m will be provided from the landing site to vulnerable buildings. The nearest building will be the hotel at the western site. The distance from the hotel building to the road (from the landing site to Resort Road) will be minimum 22m.

10.4.22 Fireworks will only be landed and transported to the storage areas during night time - i.e. when the Park is closed and there is no public occupancy within the Park.

Fireworks Storage on Site

10.4.23 Each Theme Park (Phase I and II) will have a 'Mode A' type store located in the back of house area which will store both fireworks and pyrotechnics (UN Class 1.3G, 1.4G and 1.4S). The indicative locations are shown on *Figure 10.3a*. The products will be stored in double lined wooden boxes. The maximum quantity in each store will be 4 tonnes net explosive quantity (approximately one-quarter to one-half the actual (gross) weight of the fireworks). The actual storage amount (i.e. the gross weight) will be greater than 4 tonnes.

10.4.24 The inventory in the store is based on one month's requirement. This includes approximately 30 mid-level shows with 100 kg of net fireworks for each show and 45 low-level shows with 10 kg of net fireworks and pyrotechnics for each show.

FIREWORKS/PYROTECHNICS DISPLAYS AND SHOWS

Type of Displays and Shows

10.4.25 Preliminary information on the shows proposed to be conducted at the Theme Park are given in *Table 10.4c*. The detailed design of the various shows and attractions using fireworks and pyrotechnics will be undertaken at a later stage.

Table 10.4c - Details on Fireworks Displays & Pyrotechnics Shows (for each Phase)

Show Type	Approx. NEQ per Show	Products used & Hazard class	Approx. no. of Shows per Year
Mid-level	50 to 100 kg	Candle, comets, mines & shells 5" and under (UN Class 1.3G and 1.4G)	365
Low-level	5 to 10 kg	Comets and mines (UN Class 1.3G & 1.4G)	485
Stage show	Under 1 kg	Various pyrotechnics under 200g each (UN Class 1.4G and 1.4S)	2500

10.4.26 A mid-level show will include launched shells from a secure back of house launch site and other fireworks (as shown in *Figure 10.3a*). The maximum display height will be limited to approximately 100 m and will be visible from many locations within the Theme Park. The duration of a mid-level show could vary from five to fifteen minutes depending on the show design. The number of fireworks products used will also depend on the show design but could typically involve anywhere between 100 to 1000 individual products each weighing a few grams to a few kilograms. It is assumed that the Phase I fireworks shows (mid-level) will commence at 9 pm and Phase II fireworks show will commence at 9.30 pm and Phase I and II fireworks shows will not be underway concurrently.

10.4.27 A low-level show could include both fireworks and pyrotechnics. The proposed low-level show will be similar to the Fantastic! show in Walt Disney World MGM which is conducted outdoors. The show uses approximately 6 kg of net explosive weight of fireworks and pyrotechnics in each show for certain effects. A low-level show would also contain lights, lasers, music, audio-animatronics, video displays, stage settings and performers. The duration of each show is approximately 20 minutes and operates once or twice each evening. Due to the theatrical nature of the show, such a venue could be located within any of the various lands within each Theme Park. The maximum display height will be limited to 30 m. A low-level display would not be visible outside the specific land.

10.4.28 A stage show would use only 1.4G pyrotechnics as an effect and no launched fireworks. All 1.4G pyrotechnics for use in the proposed displays have a maximum net weight of 200 g. In the event a stage show had five separate effects, a maximum of one kg of product would be required per show. The duration of stage shows could run from 15 to 30 minutes and could operate up to eight times each day at each stage. The effects are used to create a brief flash or puff of smoke; Disney currently uses stage pyrotechnics in various indoor and outdoor venues including the Beauty and the Beast and Lion King stage shows. A stage could be located within any of the Theme Park lands and such a show would not be visible outside the stage show viewing area.

10.4.29 Further description on fireworks/pyrotechnics types and effects are included in *Section 2.1 and 2.2* in *Annex I*.

Fireworks Display Site Features and Operations Associated with Fireworks Display

10.4.30 The generalised plan of a fireworks display area encompasses 4 distinct areas:

- The audience area (where the audience are, or where people could be);
- The firing area (where the fireworks are discharged from);
- The safety area (the exclusion zone around the fireworks area of sufficient size to prevent major injury/fatality to members of the audience); and
- The fallout area (the area where debris may travel following normal functioning of the fireworks). The size and orientation of the fallout area is primarily dependent on the wind strength and direction during the display.

10.4.31 The *Figure 10.3b* illustrates these areas. The extent of the safety area and fallout area depend on the type of display. This is described in later section.

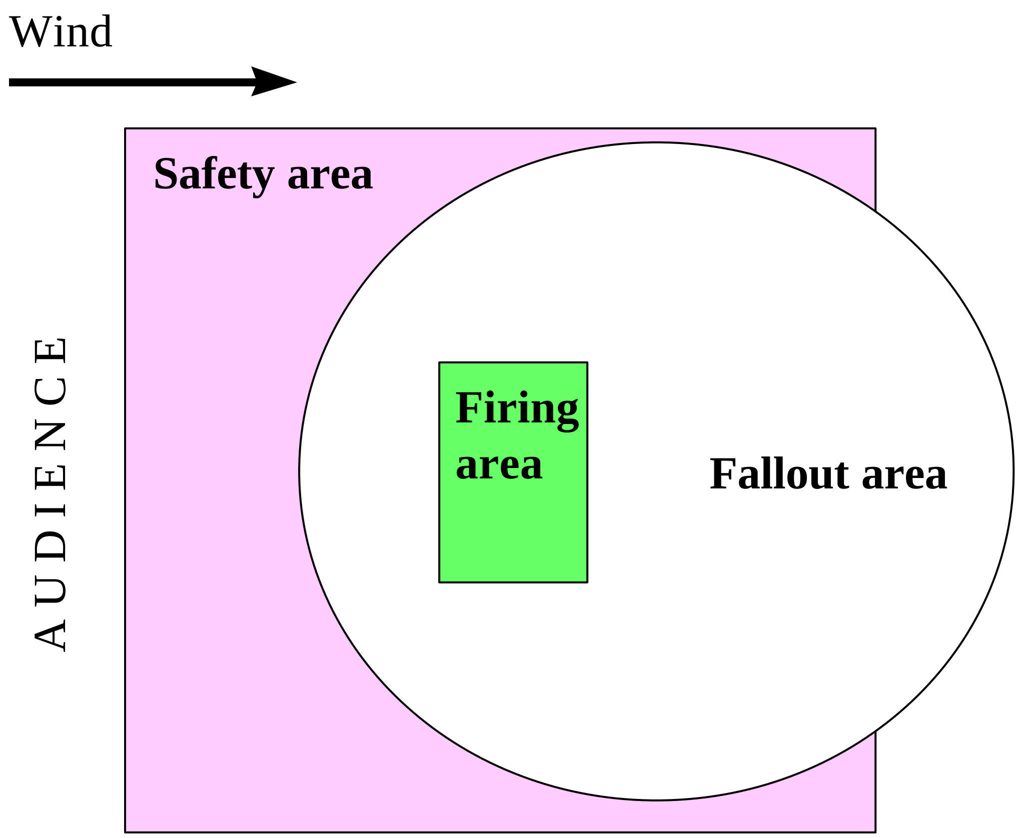

Figure 10.3b : Typical Fireworks Display Site

*10.4.32*The firing area for mid-level displays will include permanent/ semi-permanent installations for mortars or tubes from which aerial shells are fired into the air. There are many different arrangements for mortar installation. In a 'one-off' display, mortar racks (mortars racked to a strong and self-supporting wooden or metal frame) may be placed on ground or mounted on a trailer. Where displays are held daily as in the case of the Theme Park site, permanent or semi-permanent installations for mortars may be designed. This may include burying individual mortars in the ground in concrete, burying mortar racks or individual mortars in aboveground concrete troughs filled with compacted sand or mortars in steel framed launch boxes to which mortars are firmly attached.

10.4.33The launch system for the proposed Theme Park will be designed only at a later stage. However, the Theme Park operators have confirmed that they will adopt all commercially reasonable engineering measures in accordance with Government safety regulations to ensure that adjoining mortars remain in upright position following the failure of any given mortar. This will include adequate separation between mortars and rack systems constructed such that mortars are held in place by metal clamps etc. In addition, a chain link fence will also be installed around the firing site (closer to the mortars) as a ballistic barricade to catch and deflect low trajectory shells fired from a disrupted mortar. Typical height of such a fence is about 4m. The details of fence design for the proposed site will be developed at later stage.

10.4.34There will be number of mortar racks or individual mortars installed. Assuming about 200 shells are fired in a mid-level show, 200 separate mortars will be installed in racks and rows with each row containing about 10 to 20 mortars.

10.4.35 The Theme Park operator has also confirmed that all mortars will be fabricated from High Density Polyethylene (HDPE) or spiral wound Glass Reinforced Plastic (GRP). Further details on aerial shells and mortar arrangements are provided in *Section 2.3* in *Annex I*.

Display Activities

10.4.36 Fireworks displays include a number of activities; these are:

- pre-rigging;
- rigging;
- firing; and
- de-rigging.

10.4.37 Pre-rigging will involve preparatory work such as fitting igniters, chain fusing of shells etc. This will be carried out at a safe location separate from the store. Some fireworks will have igniters fitted prior to shipping while others may require igniters to be fitted at site. See further details on igniters in *Section 2.4* in *Annex I*.

10.4.38 Rigging involves installation of fireworks into firing position, connection and testing of electrical circuits. Fireworks/ pyrotechnics will be taken from the store or preparation area and erected in their relevant firing positions during the day leading up to the display. For low-level and stage displays, it may be necessary to rig several displays at one time, or to re-rig the display during breaks in the performances.

10.4.39 The Theme Park operator has indicated that aerial shells will be fired using pyrotechnic lifting charges (i.e. blackpowder lifts initiated by pyrotechnic igniters (synthetic squibs, electric fuses). Other items (i.e. not shells) will also be initiated and launched by conventional means - usually a blackpowder (gunpowder) lifting charge and a time delay fuse.

10.4.40 The operator will adopt a modern electric (electronic) firing system which allows a high degree of control over the firing of a display. Time code synchronised firing cues are used to initiate firings of individual items through either a manual or computer controlled interface. Such systems permit not only extremely precise synchronisation with music, but also permit the firer to:

- Stop the show completely in the minimum duration (where firing systems using chain firing with pyrotechnic delays between items are used, firing cannot be stopped once the chain is initiated);

- Remove shells exceeding a specified calibre at any point during the display. For instance if it is determined that 5” shells are experiencing significant debris drift it is possible to continue the display but exclude the firing of further 5” shells; and

- Remove shells of particular types - e.g. shells with long duration stars.

10.4.41 In practice a display can be halted at the cue following an incident (or at worst the cue following that). In this way it is possible to stop a display as soon as a potential fault is identified, for instance failure of adjacent mortar assemblies, thus reducing the possibility of disrupted shell launch still further.

10.4.42 De-rigging includes inspection and making safe of the firing area, removal of unfired or misfired products and their safe disposal.

SODIUM HYPOCHLORITE

10.4.43 Sodium hypochlorite will be used in ornamental waterways and fountains for disinfection and algae control purposes. The sodium hypochlorite solution to be stored at site will contain approximately 13% free chlorine. The free chlorine concentration in water features will typically range from 0.5 to 3 ppm in these features. For water features using hypochlorite, it will also be necessary to use acid to maintain a neutral pH.

10.4.44 Hypochlorite will be stored in site in tank(s). The maximum usage will be about 1000 litres per day for each Theme Park Phase. The Theme Park Operator has proposed to store about 7000 litres for each Phase. This is based on usage rates in existing Theme Parks elsewhere. The actual quantity that will be required on site is expected to be less than assumed above although this will depend on the volume of the water feature within the Theme Park and the free chlorine demand, the details of which will be finalised only later.

10.4.45 The Theme Park Operator has confirmed that hypochlorite will not be used for the Water Recreation Centre that is being developed outside the Theme Park.

10.4.46 Hydrochloric acid will also be stored on site in tank(s). The proposed storage quantity for HCl is about 4000 litres for each Phase.

10.4.47 Hypochlorite and acid will be added to the water features using an automatic controller, which constantly monitors chemical levels in the water and activates the chemical injectors as necessary.

10.4.48 Both hypochlorite and acid will be delivered by road tankers possibly from mainland China. The number of deliveries for each Phase is assumed to be two per week for hypochlorite and one per week for acid. The total number of deliveries will be 312 per year considering both Phase I and II and both acid and hypochlorite.

10.4.49 The load per delivery is assumed to be half the storage quantity, i.e. about 3500 litres for hypochlorite and 2000 litres for acid. The delivery route to the site will be the same as that described for fireworks transport. Tankers will be received at site only during night time when the Theme Park is closed to visitors.

10.4.50 The hypochlorite tank and the associated pipework are normally constructed of PVC externally reinforced with resin impregnated fibreglass, high density polyethylene or carbon steel lined with a suitable grade of rubber. The tank may be constructed as pressure vessel or non-pressure vessel. The tank will be located in open area, provided with vent and overflow lines and also a bund to contain any spills. Hypochlorite may be unloaded from road tanker by compressed air or by pump.

10.4.51 The following engineering design measures and procedural measures/ safety management system (SMS) will be adopted during detail design and subsequent operation of the Theme Park:

Design Measures

- Hypochlorite and acid tanks will be built in separate areas of the Theme Park to avoid any interaction effects between the two chemicals;

- The hypochlorite and acid tanks will be located in a secure fenced area with a locked gate. The loading point for both the tanks will also be secured such that tanker driver cannot start unloading without authorisation and presence of site personnel;
- Since deliveries will be made during night, adequate lighting will be provided for proper identification of labels on the storage tank and road tanker and also for identification of road signs leading to the storage area. The roads signs on service roads within the Theme Park will clearly identify the route to specific storage areas;
- Vent/overflow line will be located such that it is visible from the off-loading point to the operator/driver;
- Chlorine gas detectors will be installed around the tank area and near the tank vent (for both hypochlorite and acid tank system) with alarm annunciation at the tank area and also in the central control centre or other appropriate manned location within the Theme Park. Operator will stop transfer operations immediately upon receiving alarm;
- The injection system will be separate for hypochlorite and acid and there will no piping interconnection between the two systems.

Procedural/SMS Measures

- The tanks, connecting hoses and tanker contents (for both hypochlorite and acid) will be clearly labelled. This will include appropriate colour coding of the tanks and connecting hoses, danger signs and safety notices. Also, the labels will be such that it is clearly visible to the delivery personnel;
- The chemical suppliers SMS will be assessed and audited periodically by the Theme Park Operator to ensure that procedures for supply are adequate and are being followed;
- Clear procedural controls for tanker filling and unloading will be developed. This will include clear role and responsibility description of the contractor and work site personnel;
- 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 work site personnel will be present throughout the unloading operation and until it is completed and the tanker leaves the tank area. Procedures will be developed incorporating the above requirements;
- The pH of the hypochlorite solution is at least 11. Acid pH will be around 3 or less. Operating procedures will include checking of pH of tanker contents by work site personnel before it is transferred into the appropriate storage tank; and
- Training will be provided to the staff in-charge of chemical handling operations. Clear competency specifications will be outlined for the personnel;
- No acid or hypochlorite tanker will be received and/or unloaded while the Theme Park is open to visitors.

10.4.52 In addition to the above, the storage will also comply with other Fire Services requirements that may be specified by the Fire Services Department.

10.5 REVIEW OF INCIDENTS

INCIDENTS INVOLVING FIREWORKS DISPLAY WORLD-WIDE

10.5.1 Historical information for incidents and accidents identified from literature (e.g. Reuters), the Internet (especially the Pyrotechnic Mailing List) and from UK published and personal data (collated by Dr Thomas Smith an explosives consultant) is provided in *Table 10.5b*. Press reports of accidents involving fireworks are often exaggerated, and getting precise details, especially about the cause of an incident, is notoriously difficult. Tracing the type of fireworks involved from press reports is almost impossible - in the UK the public perceive anything that bursts in the air as a rocket (at professional displays the usual aerial effect is a shell), anything that goes bang is a “banger”. Any accident at a display involving fireworks is attributed to the fireworks themselves - this is particularly the case for minor eye injuries at events involving both bonfires and fireworks.

10.5.2 It is to be noted that the information includes incidents/accidents at display sites and display storage, but excludes those exclusively at manufacturing facilities. It is by no means comprehensive, but should be taken as illustrative of the types of accidents that can occur (see sections on hazard identification below). Further analysis of historical data is given in *Table 10.5a*.

Table 10.5a - Analysis of Historical Data World-wide

Index Numbers (from *Table 10.5b*)	**General nature of incident**	**Comments**
1, 8, 10, 13, 18, 20, 21, 23	Unstable firework projected into crowd	Stability of fireworks is paramount to their safety. Firework assemblies must be able to withstand disruption by adjacent firework malfunction or be disabled from subsequent firing
9	Firework disruption in multishot item leading to discharge into crowd	All multishot items should be supported by sand/other barrier to prevent this type of accident
14, 15	General debris onto crowd	General debris (shell case fragments, star debris etc.) will travel downwind. Injuries relating to this type of accident are minor.

10.5.3 Overall the rate of accidents, incidents and fatalities is extremely low. Incidents involving the general public are extremely rare, and in most serious cases are attributable to operator error or product failure. The most frequent minor incidents involve debris falling on the crowd, usually as a direct result of bad planning, the failure to have contingency plans in place to cater for changes in conditions, or the unwillingness to curtail or even cancel the display.

10.5.4 Details on incidents involving fireworks display in the UK is given in *Section 4* in *Annex I*. There have not been any deaths to the public from professionally fired displays in the UK since modern records began. There have, however, been 2 fatalities and approximately 10 serious injuries to display operators (professional and amateur) in the past 10 years. These accidents are generally attributable to operator error, and all involve the use of shells where part of the body has been placed over a functioning mortar tube. In all cases the fireworks were being lit by hand and the accident occurred during the firing of the fireworks. The design proposals at the Theme Park would preclude this type of accident to the operators.

Table 10.5b - Historical Data on Incidents Involving Fireworks Displays

No.	Year	Country	General description of accident	Public		Operators etc.		Comments	Ref	Relevance
				Fatal	Injuries	Fatal	Injuries			
1	1996	UK	Shell landed in crowd		7			Ignited on impact	1	
2	1996	UK	Firework exploded when rigged incorrectly			1		Amateur firer	1	
3	1996	UK	Firework shell struck operator while functioning			1		Amateur firer	1	
4	1997	USA	Fire on firework barge due to malfunctioning firework				10		7	
5	1997	USA	Firework malfunction and disruption of "trailer" housing fireworks	1	15			Damage caused by fragments of trailer	2,6,3	
6	1997	USA	Fire on firework barge due to malfunctioning firework			3			2,3	
7	1998	USA	Explosion of fireworks on display site				2		2	
8	1998	UK	Unstable firework projected into crowd		10				1,3	
9	1998	Australia	Disruption of firework casing leading to projection into crowd		2				6	
10	1998	USA	Rocket flying into crowd	1	9				2	No rockets are planned
11	1998	UK	8 containers exploded after electric igniter cut from firework while working in store					Igniter caught contents of one container which rapidly spread to others	1	Storage/working
12	1998	New Zealand	Debris falling onto crowd		29			Mostly minor injuries from debris		
13	1998	USA	Malfunctioning shell hit spectator on head	1				Burns to body indicate shell ignited on/after impact	2,4	Mortar tipped towards crowd. Identified worst case scenario
14	1999	UK	Debris on crowd		5			Wind change	1,3	
15	1999	USA	Debris on crowd		3				2,3	
16	1999	Australia	Limited information		9				2	
17	1999	Canada	Accident in warehouse			1	7		2	
18	1999	Kazakhstan	Rocket bursting above crowd. Other reports suggest 310mm shell	2	56				2	No rockets are planned. Shells limited to 125mm
19	1999	USA	Ignition during unloading			1			2	
20	1999	UK	Unstable firework projected into crowd		10				3	
21	1999	UK	Shell projected at unusual angle and ignited on impact with ground					Damage to windows from gravel thrown up after ignition	1,3	Identified worst case
22	1999	USA	Firework projected into storage area and subsequent explosion			3			2,5	

No.	Year	Country	General description of accident	Public		Operators etc.		Comments	Ref	Relevance
23	2000	Malaysia	Fireworks exploded too low during display		6				2	

Sources :

1 Personal investigation by Dr Thomas Smith - explosives consultant (also widespread press in UK)
2 Reuters Business Briefing
3 Information from Pyrotechnic Mailing List (PML@vnet.net)
4 Sun Newspapers
5 Associated Press
6 Workcover NSW
7 CNNNote : The term ‘explosion’ has been loosely used to describe a ‘bang’.

INCIDENTS INVOLVING FIREWORKS DISPLAY AT DISNEY THEME PARKS

10.5.5 Incident data on fireworks display have been obtained from Disney's existing Theme Parks. Disney's Theme Parks operate currently at 4 locations. The Walt Disney World in Florida consists of four Theme Parks, Magic Kingdom, EPCOT Centre, MGM Studios and Animal Kingdom. High-level shows are held in Magic Kingdom, low-level and medium-level shows in EPCOT centre, low-level shows in MGM studios and stage shows in Animal Kingdom. The Disneyland in California, Paris and Tokyo all operate only one Theme Park similar to the Magic Kingdom in Florida. Low-level and high-level shows are held both in California and Paris. The Tokyo Disneyland is operated under license from Disney by the Oriental Land Company and therefore incident data for Tokyo are not available. Additionally, a pyrotechnics show (low-level) is performed at Pleasure Island in Walt Disney World.

10.5.6 While fireworks displays and pyrotechnics shows are held daily in the Theme Parks in Florida, the shows in California and Paris are not usually held during the winter period.

10.5.7 Operating data and incident data from Disney's existing Theme Parks for the last 5 years is given in *Table 10.5c*. There have no major injuries or fatalities due to displays involving aerial shells. Considering only mid-level and high level shows over the last 5 years, Disney have conducted around 2500 shows involving about 650,000 shells.

10.5.8 Disney have been conducting fireworks displays for much longer than 5 years although detailed incident records are maintained only for the last 5 years. The total number of shells fired, since commencement to 1999, is estimated as about 3.25 million. It should be noted that the design of shows have changed many times over the years and therefore the numbers are approximate. Disney do not recall any incident of fatality during all these years.

10.5.9 Considering all types of shows, there have been over 8,500 shows, 3.1 million shells and 80 million spectators. Out of 80 million spectators, only 659 spectators filed complaints with Disney, and 657 of these complaints were for minor injuries or discomfort that were handled with ordinary first-aid. The remaining 2 injuries did not require overnight hospitalisation. It is further confirmed that more than 80% of spectator complaints involved eye irritation from pyrotechnic smoke or ash. The remainder involved minor injuries to other parts of the body. There were no deaths, or injuries requiring overnight hospitalisation, resulting from fireworks/pyrotechnics displays.

Table 10.5c - Incident Data for Fireworks Display at Disney Sites for Last 5 Years (1994 to 1999)

Details	Low-level	Low/ mid- level	High level
No. of shows	6017	625	1909
No. of shells fired	2,472,645	186,000	465,055
Avg. no. of shells/show	411	298	244
Total no. of spectators for all shows	44.93 M	4.22 M	31.82 M
No. of deaths	0	0	0
No. of injuries requiring overnight hospitalisation	0	0	0
No. of injuries requiring medical care other than ordinary first aid	2	0	0
No. of spectator complaints of minor injuries or discomfort	573	45	39
Average probability of minor injury/show	9.5 E-2	0.072	0.02
Average probability of minor injury/shell fired	2.3 E-4	2.4 E-4	8.4 E-5
Average probability of minor injury/ spectator	1.3 E-5	1.1 E-5	1.2 E-6
Note : The term shells applied to low-level shows should be interpreted as ground display devices. Shells are used only in mid-level and high-level displays.			

INCIDENTS INVOLVING SODIUM HYPOCHLORITE WORLD-WIDE

10.5.10 As part of this EIA Study, a search was carried out on MHIDAS database to identify incidents involving sodium hypochlorite. A list of incidents and the relevant details are included in *Table 10.5d*.

10.5.11 It is found that almost all the incidents were due to accidental mixing of acid with hypochlorite resulting in chlorine gas release. The reported causes of accidental mixing are unloading of acid into hypochlorite tank, piping interconnection between acid and hypochlorite tanks, and leakage from both acid and hypochlorite tanks.

10.5.12 Hypochlorite is widely used as disinfectant in swimming pools and it is not surprising therefore that most of the incidents occurred in swimming pools. All the incidents caused injuries but no fatalities. The large number of injuries can be attributed to the large number of people in the swimming pool in close proximity to the storage site.

10.5.13 Details on the quantity of chlorine released or the quantity of sodium hypochlorite or hydrochloric acid involved in the incidents are not known but based on the nature of user facilities involved in the incidents, the quantity of hypochlorite or acid storage and delivery is estimated to be in the order of 1000 litres.

Table 10.5d - Incidents involving Sodium Hypochlorite[1]

Date	Location	Injuries	Description
24/1/93	Chippenham, UK	3	450 litres of sodium hypochlorite and 40 litres of hydrochloric acid released at leisure centre.
2/4/90	Norwich, U.K	1	Wrong chemical accidentally used. Spillage of Hydrochloric Acid and Sodium Hypochlorite led to release of chlorine.
27/7/90	Manchester, U.K	7	Hydrochloric acid and sodium hypochlorite used for water treatment at swimming pool came into contact, producing chlorine. Fumes spread via air-conditioning system.
31/1/89	Wells, Somerset, U.K	8	Tanker driver connected wrong pipe and discharged hydrochloric acid into a sodium hypochlorite tank.
14/10/88	Kettering, Northants, U.K	25	Chlorine gas was formed in chlorine pump room when sodium hypochlorite (instead of hydrochloric acid) was mixed with calcium hypochlorite. The sodium hypochlorite was delivered to the pool in error.
17/5/87	Philadelphia, U.S.A	42	Leakage of separate tanks of hydrochloric acid and sodium hypochlorite formed chlorine fumes.
1/3/85	Westmalle, Belgium	25	HCl was accidentally delivered to plant and mixed with residue of sodium hypochlorite in tank producing cloud of chlorine gas.
12/2/85	Homer City, U.S.A	11	Sodium Hypochlorite reacted with sulphuric acid in a drain releasing chlorine gas cloud.
20/11/84	Slaithwaite, West Yorkshire, U.K	29	Ferric Chloride was erroneously loaded into a sodium hypochlorite (bleach) tank resulting in toxic chlorine cloud.
6/9/84	Hinckley, U.K	43	Accidental mixing of sodium hypochlorite and hydrochloric acid in swimming pool.
12/2/79	Cologne, Germany	4	Works evacuated when sodium hypochlorite tank mistakenly filled with sulphuric acid forming chlorine gas cloud.
08/3/70	Kaiserlautern, Germany	67	Pipe leak allowed mixing of hydrochloric acid and sodium hypochlorite in storage vessel and subsequent chlorine gas cloud.

10.6 HAZARD IDENTIFICATION

10.6.1 A hazard is an undesired event which may cause harm to people or to the environment or damage to property. Hazard identification is the first step when assessing the risk for a particular system, and it is the identification of What Can Go Wrong?

10.6.2 The hazards due to storage, transportation and display of fireworks have been identified based on historical review of incidents world-wide. This EIA has also adopted a formal hazard identification process, a Hazard and Operability (HAZOP) study to identify the hazards posed by storage, transportation and display of fireworks taking into account site specific and operations specific details.

HAZARDS DUE TO FIREWORKS

10.6.3 As explained in the previous section, fireworks proposed to be used by the Theme Park operator are classified as Division 1.3 and 1.4. Division 1.3 explosives 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.

10.6.4 For fireworks and pyrotechnics minor blast or projection effects refer to the blast and debris inherent in the functioning of the device.

[1] Major Hazard Incident Database, UKAEA, Silver Platter

10.6.5 Hazard Division 1.4 fireworks and pyrotechnic articles include the smaller calibre and non projectile types (including small diameter shells). Substances and articles of Division 1.4 present only a small hazard in the event of initiation or ignition. The effects are largely confined to the package and no projection of fragments of appreciable range or size is to be expected. An external fire will not cause virtually instantaneous explosion of almost the entire contents of the package.

10.6.6 There have been many incidents involving fireworks world-wide which are often described as ‘explosions’.

10.6.7 However, it is important when examining historical data of fireworks explosions to consider the following factors:

- What types of fireworks were involved (e.g. bulk storage of firecrackers may produce a large effect than even bulk storage of shells);
- Whether the fireworks were packaged, and if so what standard of packaging was employed;
- Whether it involved finished fireworks or fireworks compositions within manufacturing units;
- The actual quantity of fireworks.

10.6.8 The UK HSE have recently conducted burn trials on ISO containers containing fireworks. The trials data (as yet unpublished)is summarised in *Section 5* in *Annex I.* The trials data available at present suggests that for steel stores the main mode of structural failure is through the doors, and that the structure of the container remains substantially intact after the event and thus there is little risk from either blast or fragment throw. Although there remains a possibility of deflagrative explosion and destruction of the store, the available evidence (and examination of historical data for fireworks stores) suggests that this is an extremely rare event.

10.6.9 Previous studies by HSE on explosives transport [2],[3] have also considered substances and articles belonging to Division 1.3 (fireworks proposed to be used in the Theme Park will also belong to this hazard Division) as posing primarily a fire hazard. It is further described in these studies that ignition of substances and articles in Division 1.3 could give rise to one of two types of fires: idealised or non-idealised. An idealised fire (which poses more serious effects) is one in which the whole mass of the explosive burns simultaneously and is over in a few seconds, producing a fireball and an associated pulse of thermal radiation rather than a steady state flux. Non-idealised fire is one in which the flame propagation is hindered by the thermal inertia of packaging and the spacing between packages giving rise, in the extreme, to a number of sequential fires involving one article at a time. The thermal radiation effects from a non-idealised fire would be minimal although the duration of the fire could be very long.

10.6.10Fires involving fireworks which are explosive articles packaged in wood lined boxes are unlikely to be completely idealised although idealised behaviour could be expected from

[2] Major hazard aspects of the transport of dangerous substances, Advisory Committee on Dangerous Goods, HSE, 1991

[3] Risks from handling Explosives in Ports, Advisory Committee on Dangerous Goods, HSE, 1995

simultaneous ignition of a number of fireworks as reported in burn trials (see reference above). For the purpose of determining the worst hazard range, which will result from a fireball caused by simultaneous ignition of the contents, it is assumed that (for this study) ignition of fireworks would produce idealised fires.

10.6.11 Fireworks have also been modelled as fire hazards in the recent study on Transport of Explosives in Hong Kong [4].

10.6.12 Based on the above, it is noted that fireworks of Division 1.3 present mainly thermal radiation hazards and unlike explosives in Division 1.1 and 1.2, they do not present a mass explosion hazard or fragment hazard. However, for the purposes of this EIA Study, a conservative assumption is made that there is a low probability of a mass explosion occurring in the fireworks store at the Theme Park due to confinement within a concrete store.

HAZARD AND OPERABILITY STUDY (HAZOP) FOR FIREWORKS

10.6.13 HAZOP is one of the recognised hazard identification techniques, widely adopted to identify potential hazards for a given system or operations. The Consultants carried out a high level HAZOP study for the various operations involving fireworks - transport, storage and display. The HAZOP study considered a number of keywords relevant to fireworks operations.

10.6.14 The following keywords were adopted:

- load fall
- spontaneous ignition
- external fire
- adverse weather
- road accident
- vehicle fault/fire
- external initiation
- vehicle accident
- unauthorised access
- mixed load
- initiation
- pre-ignition
- shell failure
- mortar orientation
- debris drift
- other fireworks failure
- fireworks - unfired/misfired items

10.6.15 Further explanation to the keywords used is given in *Section 6* in *Annex I*. Specific failure modes for different fireworks items and potential hazards due to different shell effects is included in *Section 2.5* in *Annex I*. These were considered in the HAZOP as well.

10.6.16 The keywords were used to identify the causes and consequences of potential failure modes. The study considered the safeguards adopted by way of design or procedures and

(4) DNV Technica, The Risk Assessment of the Transport of Explosives in Hong Kong,, EPD, 1997

then recommended actions where necessary for further mitigation of hazards. The details of the study are included in *Section 6* in *Annex I*.

10.6.17 The action items from the HAZOP study are summarised in *Table 10.6a*. It is emphasised that most of the action items relate to development of relevant procedures. While it is accepted that the Theme Park operator will develop such procedures before the commencement of the Theme Park, the action items highlight the significance of some of the issues to be addressed by the procedures.

Table10.6a - HAZOP Study Actions

Action item	Description
A1	Identify agencies to be contacted and establish mechanisms for reporting incidents of non-recoverable load in the event of load fall into sea while unloading at the jetty
A2	Mobile phones, walkie-talkies should not be carried by persons handling fireworks
A3	Fireworks store should be kept closed during fireworks display
A4	Ensure igniters are not stored with the bulk of fireworks/pyrotechnics
A5	The site for manipulation of fireworks need to be identified. The site should be located at adequate safety distance from the store and public areas
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
A7	If vehicles such as fork lift trucks are used for transfer of goods from store to pre-rigging area or display site, it should meet appropriate specifications
A8	The maximum height of typical 4” and 5” shells could be 150 m and 175 m respectively. The 4” and 5” shells for this display site should be designed specifically to meet performance requirements (i.e., maximum burst height of 100m)
A9	Disney’s vendor supply of 4” and 5” shells must ensure items destined for other Disney locations are not delivered by error to this site unless conforming to requirements of this site
A10	Procedures to be developed if trailers are to be used for mortar installation
A11	Any mechanical system designed for varying mortar orientation should be such that it does not result in mortars orientated towards spectators
A12	Use of permanently installed mortars or other similar or safer alternatives to be considered
A13	Design and position of fence to ensure containment of low trajectory shells towards spectators as well as road (off-site)
A14	The weather conditions under which fireworks display need to be moderated should be identified in procedures based on site layout and weather data. The procedures should also identify persons responsible for making such decisions
A15	Procedures for safe handling and disposal of unfired and misfired items to be developed
A16	Procedures to be established for sweeping site after display

FIREWORKS HAZARDS CONSIDERED FOR QUANTIFICATION

10.6.18 Based on the hazards identified in the HAZOP and incident data world-wide, the following hazards are considered for further quantification:

- Transport accidents leading to fire/explosion of cargo on vehicle;
- Fire/explosion in storage; and
- Fireworks shell landing/bursting near spectators within the Theme Park or on public road.

10.6.19 The HAZOP study has examined the various modes of failure that could result in an incident involving the cargo in a fireworks road vehicle or fireworks in a storage area. The worst outcome of all such incidents is most likely to be fire although the potential for an explosion is also considered. The frequency of a fire or explosion incident during transport and storage and its consequences are modelled in the later sections.

10.6.20 The HAZOP study has also examined the various modes of failure during a fireworks display. The incident that could potentially cause a fatality to the public is identified as that involving an aerial shell discharge in mid-level fireworks display.

10.6.21 The risk of a fatality incident due to discharge of 'other fireworks items' used in mid-level, low-level and stage displays is considered to be negligible (i.e., less than 10^{-9}) per year on account of the following safety measures:

- adequate separation distances between the display area and the audience will be maintained (see *Section 3.6* in *Annex I*). In addition, all safety measures outlined in the relevant codes, such as NFPA 1123 and 1126 will be adopted;
- members of the audience will not be invited on stage during the course of discharge of fireworks or pyrotechnics;
- the net explosive quantity per firework is very low. The total net explosive quantity per low-level show will be 5 to 10kg and for stage show under 1kg. The net explosive quantity per firework item therefore will be very low. The quantity of fireworks items per show is also low;
- the nature of fireworks items used for such shows/displays are such that even if they are accidentally discharged towards the crowd due to disruption of their orientation would only result in burning debris on the crowd which will not cause any fatality although there is some injury potential. This can be further elaborated as follows:
- the chemistry is carefully controlled; for example use of nitrocellulose as a fuel/oxidant which produces a very low temperature flame;
- fireworks items are usually erected in purpose built rigs which are highly over-engineered;
- quality control to ensure that 'other fireworks items' of design commensurate with the safety distances will only be used. Quality control on stage pyrotechnics is generally very good as they are relatively high value items;

10.6.22 Considering the above, only the incident involving a shell landing/bursting near spectators/public areas is further quantified in the later sections. The potential causes and circumstances leading to this incident is further described below.

Shell Landing/Bursting Near Spectators

10.6.23 The potential for shell landing/bursting near the audience when fired from a mortar at its design orientation is considered to be very low as the separation distances are adequate for such an event. Mortars are oriented either vertically or inclined to an angle of about 5 degrees from vertical away from the audience. Mathematical calculations for shell ballistics presented in *Section 7* in *Annex I* show that 'dud' shells are expected to fall back to ground within few tens of metres from the firing point. However, in reality, dud shells scatter about the fallout area and their actual trajectory is different from the predicted trajectory 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 (5). The separation distances should be adequate even accounting for drift effects.

10.6.24 The most significant injury/fatality potential to the public arises where a shell lands and or bursts in or near the audience. This could occur when a shell is discharged from its mortar

(5) Kosanke, K.L and Kosanke, B.J, Aerial Shell Drift Effects, Selected Pyrotechnic Publications of K.L and B.J. Kosanke, Part 2, 1992

which is in unsafe orientation (this is defined as orientation greater than 5 degrees from vertical).

10.6.25 Mortar orientation may become unsafe due to the following:

- mortar orientation unsafe and operator fails to rectify orientation prior to loading;
- mortar support fails during firing; or
- shell failure within mortar ruptures mortar and disrupts the orientation of adjoining mortars.

10.6.26 Mortar orientation may become unsafe for a number of reasons and these include displacement due to firing, incorrect installation following maintenance or redesign of the show or mechanical failure for example, if trailers with hydraulic jacks are used. The procedures require that operator ensure that the orientation is safe prior to loading of shell. Human error could however, result in shell being fired from mortar in unsafe orientation.

10.6.27 Mortar support failure is considered to be very low for the arrangement proposed for the Theme Park where mortars racks are either buried in sand within concrete troughs or mortars placed in steel framed launch boxes to which mortars are firmly attached.

10.6.28 A shell may burst prematurely within its mortar and lead to disruption of adjacent mortars such that it results in unsafe orientation. Premature failure of the shell may occur if the delay fuse is faulty and does not provide a sufficient delay. Most frequently such a mode of failure is due to incorrect fitting of the delay fuse rather than a faulty delay fuse itself. If fire can be transmitted from the lifting charge to the bursting charge directly through a fault in construction the bursting charge will ignite while the shell is still in the mortar. This may lead to rupture of the mortar and possible disruption of adjacent mortars.

10.6.29 The potential for a shell landing and or bursting near audience when fired from a disrupted mortar will then depend on whether the shell bursts at normal delay time and the angle of orientation of the mortar.

Shell bursts normally but near audience

10.6.30 If a shell is ejected from a mortar at a low angle and bursts at normal delay time, it is possible that it will burst within, or in close proximity to, the audience area. In this case the horizontal distance travelled by the shell, and the altitude at which the shell functions is dependent on the initial angle of launching.

10.6.31 In order to examine this further, the trajectory of a shell fired at various mortar angles is calculated from equations described in *Section 7* in *Annex I*. Considering drift distances, the results show that for all mortar angles between 5 degrees from vertical towards audience to 5 degrees from horizontal, the dud shell could land beyond 100m (see *Figure 10.5a*. The horizontal range shown in the figure. however, does not include drift effects). However, the time of flight (considering drift effects) is greater than normal burst times for all angles except low angles of less than about 15 degrees from horizontal. Normal burst times are taken as 3s, 3.5s and 3.5 to 4s for 3”, 4” and 5” shells respectively. Hence only in the case of low angles (i.e., less than 15 degrees from horizontal), the shell may burst normally but near the audience. At all other angles, the shell will burst at a significant height above crowd and therefore only debris will be transported to the crowd. See *Figure 10.5a*.

10.6.32 In order to prevent low trajectory shells (i.e. less than about 15 degrees from horizontal) bursting near audience, the firing site in the proposed Theme Park will be enclosed by a fence which will be constructed of suitable height so as to catch all low trajectory shells. Typical height of fence is 4m. Considering that mortars will be placed in rows (extending from the fence), the shell trajectory angle that will be contained by the fence from a mortar placed about 10m and 2m from the fence is about 20 and 60 degrees from horizontal respectively.

10.6.33 Even if the fence was to fail in containing the shell (which is considered to be very low, say, probability of less than 1in 1000 based on Disney's experimental trials), it is likely that the shell may either burst due to impact with the fence or its velocity significantly reduced that it will fall on to ground before reaching the crowd. This scenario is therefore not modelled further.

Shell fails to burst normally & bursts on impact near audience

10.6.34 If a shell fails to burst at its normal delay time, the intact shell is likely to fall outside the safety area of about 100m when fired from a disrupted mortar, as discussed earlier. This could result in the following outcomes:

- the shell could strike an individual causing severe injury or death due to impact. The impact energy of a shell weighing about 250 to 750g falling from a height of 25 to 75m is high enough to cause fatality if it strikes on the head; or
- the shell could ignite on ground causing local injury or death by the effects of blast (limited to very close proximity) or by fire.

10.6.35 A shell may fail to burst at the intended time if the delay fuse fails to light or is extinguished in flight leading to a "dud" shell (other terms are "blind" or "black"). The failure of modern delay fuses is however, extremely rare, and the common practice of fitting multiple delay fuses independently to medium (often 2 delay fuses to 4" and 5") and large (often 3 delay fuses to 6" and above) shells has reduced this mode of failure.

10.6.36 Nevertheless, if a shell does fail to burst as intended there is a possibility that it will ignite on impact through one of two possible mechanisms:

- Direct energy applied to the stars and other components within the shell igniting the contents by friction or shock;
- Fragmenting of the shell on impact and ignition of the contents by frictional effects or by some residual fire (smouldering) of the delay fuse or shell casing; or
- delay fuse igniting after the intended time.

10.6.37 The scenario where the shell fails to burst normally when fired at angles that are unsafe is quantified further by fault and event tree analysis in later section.

HAZARDS DUE TO SODIUM HYPOCHLORITE

Physiological Properties

10.6.38 As explained earlier, sodium hypochlorite is classified as corrosive. Contact with the skin causes burns unless washed off immediately. When in the eye, it can cause severe damage even for a short duration. If inhaled, the mist or vapour causes irritation to the nose, throat and respiratory tract. The solution if ingested will cause severe irritation and corrosion of the mouth, throat and digestive tract. The effects described above are relevant for persons coming in direct contact with the solution.

Chemical Properties

10.6.39 Sodium hypochlorite dissociates to hypochlorous acid which is the chemical that acts as the bactericide and algacide in water. The strength of sodium hypochlorite is therefore expressed in terms of its ‘available chlorine’ or ‘free chlorine’ content. The available chlorine content is a measure of the oxidising power of sodium hypochlorite solution and may be defined as the quantity of chlorine equivalent in oxidising power to the hypochlorite present. The term ‘free chlorine’ does not imply presence of chlorine in dissolved form that could be released due to increase in temperature or other causes.

10.6.40 Sodium hypochlorite is decomposed by acids giving a rapid evolution of chlorine gas. It also reacts with many oxidising agents such as hydrogen peroxide to liberate either oxygen or chlorine.

Decomposition Reaction

10.6.41 Sodium hypochlorite solutions decompose on standing. Six major factors affect the decomposition of sodium hypochlorite. These are:

- initial concentration of the hypochlorite;
- temperature of the solution;
- concentration of certain metallic impurities e.g. Copper, Nickel, Cobalt;
- alkalinity or pH value of the solution;
- exposure to light; and
- use of thickeners.

10.6.42 Decomposition occurs in two main ways:

$$3NaOCl \longrightarrow 2NaCl + NaClO_3 \quad (1)$$
$$2NaOCl \longrightarrow 2NaCl + O_2 \quad (2)$$

10.6.43 When solutions of a good commercial quality are stored in the dark over 90% of the decomposition occurs via the chlorate forming reaction (1) and 5-10% by the oxygen forming reaction (2). The effects of the various factors are given below:

- The rate of decomposition increases with the increase in ionic strength of the solution;
- A rise in temperature of about 5^{o} C approximately doubles the rate of decomposition;
- The presence of certain metals or their compounds can also reduce the stability of the solution;
- Sodium Hydroxide is added to the sodium hypochlorite solution to maintain its alkalinity. A pH of 11 is essential to maintain the stability of the solution. A drop in the pH will lead to the solution losing its stability; and
- Blue and Ultraviolet light accelerate the decomposition of the hypochlorite solution by increasing the rate of both the decomposition reactions.

Hazards due to Sodium Hypochlorite Considered for Quantification

10.6.44 As seen from the properties of sodium hypochlorite and from the review of incidents, the main hazard due to storage of sodium hypochlorite is accidental reaction with acids resulting in evolution of chlorine gas. Since hydrochloric acid will also be stored on the site, and both acid and hypochlorite will be received on site by road tankers, accidental mixing could occur if acid tanker is inadvertently unloaded into hypochlorite tank or hypochlorite is inadvertently unloaded into the acid tank.

10.6.45 The release of chlorine is hazardous as chlorine is a toxic gas. Symptoms caused by inhalation of chlorine include headaches, pain, difficult breathing, burning sensation of the chest, nausea and watering of the eyes. If exposed to chlorine at 30ppm for one minute, severe toxic effects would occur.

10.6.46 The frequency of occurrence of such an event and the resulting consequences are quantified in the later sections.

10.7 FREQUENCY ANALYSIS

10.7.1 This section of the report presents the approach adopted for estimation of the frequency, i.e. the likelihood of occurrence of an undesired event. There are basically two approaches to frequency estimation. The general approach is to estimate the likelihood of an undesired event from historical data world-wide on similar operations or systems. Where such data is limited and therefore is not statistically significant, the alternate approach is to synthesise failure rate by use of fault tree/event tree techniques.

10.7.2 For fireworks, historical data has been used to derive frequency of fire or explosion incident during transport and storage. To derive the frequency of shell landing and/or bursting on crowd, fault tree and event tree techniques have been adopted although references to historical data have also been made.

10.7.3 It should be noted that even for storage and transport of explosives, historical data on incident frequency is rather limited since the controls on explosives storage have largely been based on Quantity-Distance (QD) principles (which set out safety distances for different types of explosives and quantity) and licensing rather than QRA. So no attempt was made to derive incident frequencies until recently when the Health and Safety Executive (HSE) in the UK carried out studies on risks due to transport of explosives and the new COMAH (The Control of Major Hazards) regulations were introduced in the UK requiring risk assessments for explosives storage.

10.7.4 There is considerable uncertainty however, on the frequency values derived in these studies due to limited data. For example, explosives of different hazard divisions and types present varying degrees of risk of say accidental initiation but there is not sufficient data to determine incident frequency for each type.

10.7.5 Also, there is no published data on frequency of incidents involving storage and transport of finished fireworks. Although incident frequency derived for other explosives can be adopted for fireworks, it is however, reasonable to ask whether fireworks pose greater risk of accidental initiation as compared to other explosives. The argument in favour of using of similar frequencies for fireworks and other explosives is that fireworks (which are widely transported by sea and road) present similar hazards, if not lower as compared to other explosives.

10.7.6 Incident data on fireworks storage available from Disney is also limited. The total operating experience of Disney in this regard is only about 100 store years which is not sufficient to derive statistically meaningful results. Disney have however reported one incident of accidental initiation during handling, i.e. when goods were being moved between magazines in a fork lift truck. A pallet of shells ignited resulting in loss of a pallet and extensive damage to the forklift.

10.7.7 For incidents associated with sodium hypochlorite, the frequency value is synthesised using fault trees and generic human error probabilities.

FREQUENCY OF FIRE/EXPLOSION INCIDENTS DURING TRANSPORT

10.7.8 Fires on explosives vehicles are considered in two categories namely crash fires and non-crash fires. Crash fires are related to collisions whereas non-crash fires have cab/engine fire, smoking materials, arson and tyre fire as their cause. The ACDS(6) study has derived a value of 2×10^{-9} per vehicle-km as the fire frequency while the Explosives Transport QRA (7) has derived a value of 1.5×10^{-9} per vehicle-km which is also based on the ACDS study but factored to account for Hong Kong conditions.

10.7.9 In a recent study by FSD (8), the frequency of road traffic accidents involving medium and heavy goods vehicles in Hong Kong was estimated as 5.8×10^{-7} per vehicle-km. Not all road accidents are serious. The probability of a major accident was estimated as approximately 0.01. Assuming that an explosives vehicle involved in a major accident will lead to fire, the frequency of fire during transport can be derived as 5.8×10^{-9} per vehicle-km. This value is adopted here and it is about 3 times higher than the values derived in other studies referred above.

10.7.10 The distances from the landing site to the stores at the Theme Park Phase I and II are 0.86 km and 3.66 km, respectively. Based on 2 deliveries per month to each store, the overall frequency for fires due to transport by road is derived as $5.8 \times 10^{-9} \times 2 \times (0.86 + 3.66) \times 12 = 6.3 \times 10^{-7}$ per year.

10.7.11 It is further assumed that there is a 10% probability of an incident leading to an explosion. The frequency of an explosion event during transport is therefore derived as 6.3×10^{-8} per year for the given number of deliveries and route length.

10.7.12 The values derived above are considered for modelling the effects on road users.

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(6) Advisory Committee on Dangerous Substances (ACDS), Major Hazard Aspects of the Transport of Dangerous substances, HSC 1991

(7) DNV The Risk Assessment of the Transport of Explosives in Hong Kong, EPD 1997

(8) ERM-Hong Kong, Conveyance of Dangerous Goods by Vehicles: UN Class 4 to 9, FSD, 1999

10.7.13 The frequency of fire and explosion incidents during transport with potential to affect the hotel development adjoining the road is derived as 1.3 x 10^{-7} per year and 1.3 x 10^{-8} per year respectively (this is based on route length of 450m along the hotel development).

FREQUENCY OF FIRE/EXPLOSION INCIDENTS IN STORAGE

10.7.14 Merrifield and Moreton[9] have recently examined the historical accident record for explosives storage in the UK during the period 1950 to 1997. Analysis of historical data show that there have been no incidents involving storage of finished and packaged high explosives in secured premises. An incident rate of 1 x 10^{-4} per store-year has been derived taking a 90% confidence interval and 20,000 store years.

10.7.15 The incident rate adopted in other Hazard Assessment studies [10] in Hong Kong for storage of explosives vary from 1 x 10^{-5} (for storage of Division 1.1 cartridged explosives (water gel)) to 1 x 10^{-4} per year (for storage of detonators).

10.7.16 For the proposed storage of fireworks in the Theme Park, an incident frequency of 1 x 10^{-4} per store year is adopted. An incident involving fireworks is most likely to result in a fire and therefore the value derived is considered as frequency of fire. In order to account for the probability of an explosion incident involving fireworks, a frequency of 1 x 10^{-5} per store year is assumed for an explosion event.

FREQUENCY ESTIMATION OF SHELL LANDING/BURSTING ON SPECTATORS

10.7.17 The frequency of an event involving shell bursting on spectators is synthesised using fault tree and event tree analysis.

10.7.18 Fault tree analysis examines the logical relationship between the circumstances, equipment failures and human errors which must exist in order for the top event of interest to occur. Event Tree Analysis analyses how the initiating event (which is the top event of the fault tree) may lead to a number of different outcomes, depending on for example, the performance of safety systems.

10.7.19 The top event for the fault tree (which is also the initiating event for the event tree) has been defined as ‘Shell fired from mortar in unsafe orientation’. The fault tree and event tree are shown in *Figures I8a* and *I8b in Section 8 of Annex I*. The explanation for the assignment of values to the basic events in fault tree and branch probabilities in the event tree is provided in *Table I8a* and *I8b* respectively in *Annex I*.

10.7.20 Analysis of the fault and event trees gives the following result:

- The probability of a shell fired from a disrupted mortar is approximately 1.2 x 10^{-5} - i.e. 1 in 84,000 shells fired. This equates to a frequency of 1 shell fired in this manner in approximately 2 years given the number of shells and frequency of the proposed displays at the Theme Park development (2 shows per day times 365 days per year times 200 shells per show);

([9]) R. Merrifield and P.A. Moreton, An examination of the major-accident record for explosives manufacturing and storage in the UK. Journal Hazardous Material, A:63, 1998, pp 107-118.

([10]) Mott McDonald Hong Kong, New Explosives Complex at Kau Shat Wan, Hazard and Environmental Assessment, CED, 1992

- The probability of a fatality incident due to shell burst in the audience area is 2.2×10^{-12} per shell fired. The corresponding frequency is 3.2×10^{-7} per year for the given the number of displays;

- The probability of a fatality incident due to being hit by an unburst shell is estimated as 2.1×10^{-10} per shell fired. This corresponds to a frequency of 3.1×10^{-5} per year for the given number of displays. The probability of fatality given an incident is however, considered to be much lower in this case than for shell burst near audience (see later section).

10.7.21 In order to compare the above synthesised results with historical data, world-wide historical data on fireworks displays and fatality incidents is used. The historical data for Disney (described earlier) is limited and there have been no fatality incidents in Disney sites.

Historical Data from UK and World-wide

10.7.22 As described earlier, some 20,000 professional and semi-professional fireworks displays are carried out each year in the UK. Approximately 14 million shells are estimated to have been fired in the UK in the 5 year period 1994-1998 (see *Section 4* in *Annex I* for details) with no fatalities or major injuries to spectators during this period. Assuming 0.7 incidents (corresponding to 50% confidence level for 0 incidents), this gives an incident probability of about 5×10^{-8} or 1 in 20 million shells fired.

10.7.23 It is assumed that world-wide, the number of fireworks displays is about 10 times the value derived for the UK. Over a 5 year period the number of shells fired is derived as 140 million and during this period there have been 5 audience fatalities (as given in *Table 10.5b*). This gives a frequency of 3.6×10^{-8} audience fatality per shell fired or 1 audience fatality in 28 million shells fired.

10.7.24 The world-wide figure can be indirectly verified from trade statistics on fireworks of type aerial shells. Most of these are exported from mainland China, significant quantities of which pass through Hong Kong. The Hong Kong trade data on all fireworks provide a re-export value of HK$343 million for the year 1997. The proportion of aerial shells amongst fireworks is not known nor is the data on quantity of fireworks available. The cost of an aerial shell is about HK$10 and the total value for 140 million shells is HK$1400 million over 5 years or HK$280 million per year. Although fireworks do not all include aerial shells, the actual number given the data limitations is expected to be within a range of 2 of the estimated figure.

10.7.25 The probability of a fatality incident due to a shell burst near audience derived as 2.2×10^{-12} per shell fired for the proposed Theme Park, which is 4 orders of magnitude lower than that derived based on world-wide data which is 3.6×10^{-8} per shell fired.

10.7.26 On whether the calculated values are reasonable given the world-wide experience, this is discussed in the following paragraphs. Based on the analysis presented earlier, fatality incidents world-wide can be attributed to the following scenarios:

- low trajectory shells bursting at normal times within the crowd;
- low trajectory shells that fail to burst normally but burst on impact;
- high trajectory shells that fail to burst normally but burst on impact.

10.7.27 If it is assumed that the world-wide incidents were all due to low trajectory shells bursting normally, then in the proposed Theme Park, these will be caught by the fence (which is not provided for one-off displays covered in the world-wide data). If it is further assumed that the probability of fence failing to catch a shell is about 1 in 10,000, then the historical frequency adjusted for provision of fence will be similar to the derived frequency for the Theme Park. This would however, imply that no credit is due for improved mortar installation and the expected reduction in probability is entirely due to the fence.

10.7.28 The latter two cases (of shell failure to burst normally) involve fuse failure and fuse failure probability is estimated as 1 in 10,000 (based on their current operations, Disney have confirmed that about one to two 'dud' shells are found on average over a 3 month period involving about 20,000 shells). If it is assumed that world-wide incidents were all due to high trajectory shells that fail to burst normally but burst on impact (which is considered to be unlikely given the low fuse failure probability), the 4 orders of magnitude difference between world-wide estimates and the derived results will be justifiable only if credit is taken for improved mortar installation.

10.7.29 This is further supported by the nature of mortar arrangements in one-off displays which involve mainly self-supporting mortar racks rather permanent arrangements as proposed in the Theme Park . The former has greater potential to result in mortar orientation towards crowd.

10.7.30 Either way, the lower value for the Theme Park is justifiable on account of the additional precautions taken by Theme Park Operator such as design of mortars to prevent toppling and provision of a fence to catch low trajectory shells. Those shells that go over the fence require time fuse failure also to occur for the shell to burst near or on the ground.

10.7.31 These two additional safety features (firing site design and wire-mesh fence) that will be adopted in the proposed Theme Park more than compensate for the large number of displays fired at the site - most fireworks displays in the World are "one-off" events where these precautions are not cost effective to achieve.

10.7.32 Given these additional measures, the most likely outcome of a shell being fired at an angle towards the crowd is minor debris fall on the crowd - this result confirms both Disney's own accident data and the general perception of industry experts (see *Section 10* in *Annex I* on hazards due to debris). However, firing at an angle is only a small contributing factor to production of debris fall on a crowd since such debris (although in minor quantity) are most often produced by wind drift while firing at normal orientation.

FREQUENCY OF INCIDENTS INVOLVING SODIUM HYPOCHLORITE STORAGE

10.7.33 Accidental mixing of acid and hypochlorite could result in generation of chlorine gas. As explained earlier, this could occur due to the following reasons:

- a road tanker carrying HCl is mistakenly pulled in near the hypochlorite tank and is unloaded (right product in wrong tank);
- similar to the above error, a road tanker carrying hypochlorite is unloaded into acid tank;
- wrong product is delivered, i.e. acid is delivered instead of hypochlorite or vice versa (wrong product in right tank).

10.7.34 Other possible causes for accidental mixing such as due to piping connections between the two tanks or failure of both the tanks (if located nearby or in the same bund) are not considered as the layout and design of the system will be such that these incidents are ruled out.

10.7.35 While it is assumed that the Theme Park Operator will develop suitable procedures and design to minimise the potential for accidental mixing during unloading operations, nevertheless such incidents could occur due to gross human error.

10.7.36 A simple fault tree has been developed to quantify the human error probability resulting in the top event which is defined as 'operator error resulting in mixing of acid and hypochlorite' and subsequent chlorine release. The fault tree is shown in *Figure I8c* in *Annex I*. The explanation for the assignment of values for the basic events in fault tree is given in *Table I8c* & *I8d* in *Annex I*.

10.7.37 The probability of this event is made up of the likelihood of driver/operator making an error and failing to recover that error in time.

10.7.38 Recovery failure here is taken as the driver/operator failing to detect the error and actually starting to unload the tanker to a point where sufficient product is pumped to cause chlorine to start to be released.

10.7.39 Since at this stage the quality of the various performance shaping factors (i.e. detailed procedural steps, design and organisational factors) are not known, human error probability is only modelled at a high task level using generic values as given by Hunns and Daniels 1980[(11)]. The analysis however, assumes a very high quality of all relevant performance shaping factors (i.e. that design and operation factors are optimised with respect to high operator reliability).

10.7.40 Based on the high level analysis, the probability of operator error resulting in mixing of acid and hypochlorite is estimated as 2×10^{-8} per unloading operation. While it is known that tanker-tank transfer operations are carried out on large scale, widely across the industry and comparatively, incidents such as accidental mixing of incompatible chemicals are reported to be very few, there are no readily available historical data to verify if the estimates derived in this study are reasonable.

10.7.41 It is therefore assumed that appropriate and reasonable design measures will be adopted to eliminate the potential for mixing (the event - right product in wrong tank). One such measure is to design specific hose connections (such as type and size of coupling and size of hose etc.) for hypochlorite and acid unloading such that an acid tanker cannot be connected to the hypochlorite unloading point and similarly a hypochlorite tanker cannot be connected to the acid unloading point. Therefore the event, right product in wrong tank can be ruled out.

10.7.42 However, the potential for the other event, wrong product in right tank, could still occur and the estimated value of 1×10^{-8} per operation is considered reasonable for this case.

([11]) Hunns, D.M and Daniels, B.K., The Method of Paired Comparisons, Proceedings 6th Symposium on Advances in Reliability Technology, Report NCSR R23 and R24, UK Atomic Energy Authority, 1980.

10.7.43 Assuming 3 deliveries per week for each Phase, the overall frequency of chlorine release is derived as $10^{-8} \times 312 \equiv 3 \times 10^{-6}$ per year.

10.7.44 There is another opportunity for error recovery and this is after the product has started being unloaded in error, and where chlorine is detected (through chlorine gas detectors), allowing the operator to realise the error and shut down immediately. Provision of chlorine gas detectors as assumed in the base case design will further alert the operator in time to stop the transfer operation. This is further considered in *Section 10.10.7*.

10.8 CONSEQUENCE MODELLING

10.8.1 This section of the report presents the approach adopted in modelling the consequences of the following events :

- fire and explosion incidents during transport and storage of fireworks;
- fireworks shell landing/bursting on spectators within the Theme Park or on road;
- chlorine release.

10.8.2 Consequence models are used to determine the hazard ranges for fireball, explosion and toxic events. Vulnerability models are used to determine fatality probability at various distances from the incident site. Based on the above the expected number of fatalities is estimated.

10.8.3 Since both storage and transport of fireworks involve similar quantities (i.e. 4 tonnes NEQ), the consequences would be similar although the number of fatalities will be different depending on the number of persons present within the hazard ranges.

10.8.4 It has been described earlier that incidents involving fireworks of Hazard Division 1.3 and 1.4 will mainly result in a fire. Assuming an idealised fire involving the entire contents, this will result in a fireball. There may however, be potential for blast effects due to rapid deflagration upon ignition and therefore the effect distances due to explosion are also derived.

10.8.5 In the case of shell burst on crowd, the effects are modelled as a fireball.

10.8.6 The toxic effects of chlorine release are modelled based on estimated quantity of chlorine release, dispersion modelling and vulnerability modelling based on probit equations.

FIREBALL EFFECTS FROM STORAGE/TRANSPORT

10.8.7 The hazard ranges due to a fireball are estimated as given in *Table 10.8a*. The models used for determining the hazard ranges is described in *Section 9.1* in *Annex I.*

Table 10.8a - Hazard Distances for Thermal Radiation from Fireballs

Percentage Fatality	Distance from Centre of Fireball (m)
1%	40
50%	28
100% (Fireball radius)	17

10.8.8 The duration of fireball is 2.9 seconds and the diameter is 34 m. It has been assumed that ignition will result in an idealised fire giving rise to a fireball which burns within about 3 seconds. The actual duration is however, expected to be longer due to the packaging and also due to insufficient oxygen as a result of confinement within the concrete store/transport vehicle but then the size of the fire and thermal flux will also be lower than estimated. The estimated hazard ranges may therefore be considered to be conservative for the hazards posed by fireworks.

10.8.9 From the hazard ranges for fireball, it can be seen that the public (both Theme Park visitors and off-site public) will not be affected by the incidents involving storage of fireworks due to the 100 m safety distance to spectators and 50 m to the road.

10.8.10 However, fireball incidents during transport could engulf other passing vehicles on road. Similarly, fireball incidents during transport could also affect the hotel development. The estimation of fatalities due to fireball events during transport is given in *Section 9.3* in *Annex I.*

FIREBALL EFFECTS FROM SHELL BURST

10.8.11 As explained earlier, a single 5" fireworks shell typically contains 100 g flash powder (or similar) as bursting charge and 400 g of star composition. A 5" shell has a design burst radius of approximately 17 m which is the distance burning stars from the fireworks can be expected to travel. Burning stars could cause injury but unlikely to cause fatality. However, initiation of bursting charge could give rise to a fireball.

10.8.12 Wharton and Merrifield [(12),(13)] have investigated the fireball diameter for various fireworks compositions (loose compositions) and found that for a 1kg of loose fireworks composition, the fireball diameter is about 1 to 2 m for star/flare composition, about 3 m for gunpowder and about 5 m for flash composition.

10.8.13 Extrapolation of the results of Wharton and Merrifield to flash composition of 100 g, show that the fireball produced by this amount would have a diameter of approximately 2 m.

10.8.14 The maximum number of persons within the fireball diameter is estimated as 6 to 8 assuming a density of 2 persons /m^2 for densely packed crowds. Persons within the fireball could suffer severe burn injuries or even fatality. The direct effect on people outside the fireball radius is assumed to be not significant. However, there is potential for 'panic' in the crowd following a shell burst incident leading to stampeding. Since the duration of fireworks shell burst will be a maximum 5 seconds which is less than typical reaction time for persons, the 'panic' effect is considered to be small. This was also found to be the case in the incident with the highest fatality involving fireworks burst in crowd. This occurred in Kazakhstan (where 2 persons were killed and many injured) and it reported that there was no panic and the injuries were all due to facial, neck and chest

(12) Wharton, R.K sand Merrifield, R, Thermal Hazards from Accidental Ignition of Pyrotechnic Compositions, Journal of Pyrotechnics, 6, 1997

(13) Wharton, R.K sand Merrifield, R, Potential Fire and Explosion Hazards of a Range of Loose Pyrotechnic Compositions, US Dept. of Defense, Explosives Safety Board, 27th Explosives Seminar, 20-22 Aug, 1996, Sahara Hotel, Las Vegas, Nevada, USA.

burns. Estimation of fatalities due to shell burst in crowd is given in *Section 9.3* in *Annex I*. There is also potential for fatality due to shell impact on person which is also explained in *Annex I*.

EXPLOSION BLAST EFFECTS FROM STORAGE/TRANSPORT

10.8.15 The main effects of an explosion are the generation of a blast wave and fragment effects from blast. Blast effects could cause injury to persons outdoors as well as indoors due to building structure damage. The nearest buildings open to visitors within the Theme Park will be 100 m from the fireworks store. Such buildings if any, will be low rise to medium rise, constructed of light weight and designed for staging indoor attractions. Otherwise, the visitors will be mostly in the open but at a distance of 100 m from the store.

10.8.16 The hazard distances due to blast effects for persons indoors and outdoors are calculated separately. The details are given in *Section 9.2* in *Annex I. Table 10.8b* below shows the calculated damage radii for buildings based on TNT equivalent of 925 kg. The fatality probability corresponding to R(A), R(B) and R(Cb) are 0.62, 0.086 and 0.009 respectively.

Table 10.8b - Building Damage Radii for Explosion

Load Size of TNT (kg)	Damage Radii(m)		
	R(A)	R(B)	R(Cb)
925	31	45	79

10.8.17 From *Table 10.8b*, it can be seen that the distance to 1% fatality for people indoors is about 80 m. All indoor attractions within the Theme Park are located further than this distance and therefore the hazards due to blast wave is not considered significant.

10.8.18 The potential for blast wave generation due to storage incidents can however, be further minimised by providing explosion relief such as weak roof. It is understood that Disney have adopted such design elsewhere and are currently discussing this option with the Commissioner of Mines (the existing requirements for explosives store requires a concrete store including the roof).

10.8.19 Along the transport route, the nearest building will be the hotel development at the south-west corner of the site over an area of 200m by 300m. This will be located about 75 m from the landing site (in accordance with the requirements from the Commissioner of Mines for separation distances from loading/unloading operation areas to buildings). However, along the transport route, the hotel development will be separated only by a 5m high and 22m wide berm. Additional separation from the road to the building will depend on the detail design.

10.8.20 The estimation of fatalities due to explosion events during transport (based on hazard distances given in *Table 10.8b*) is given in *Section 9.3* in *Annex I*.

10.8.21 The hazard distances to fatality for persons outdoors due to lung haemorrhage and body translation are given in *Table 10.8c*. The hazard distances are based on TNT equivalent of 925 kg. The details are given in *Section 9.2* in *Annex I*.

Table 10.8c - Hazard Distances for Persons Outdoors due to Blast Effects

Damage Produced by Blast	Hazard Distance (m) for 925 kg TNT equivalent
1% fatality due to lung haemorrhage	30
1% fatality due to body translation	7

10.8.22 The minimum separation distance between the store and the spectators is 100 m which is outside the hazard range for blast effects from the store.

10.8.23 Passengers in passing vehicles would be affected by explosion events during transport. Passengers in vehicles are considered outdoors but in addition to outdoor effects they could also suffer injury due to flying glass fragments. Since the hazard ranges for blast effects on persons outdoors are not significant in relation to thermal effects (100% fatality in 17 m radius and 1% fatality in 40 m radius), risks due to blast effects during transport are not considered separately.

CHLORINE RELEASE MODELLING

10.8.24 The quantity of chlorine that may be released due to accidental mixing of acid and hypochlorite is estimated based on the following:

10.8.25 In strongly acid solutions, hypochlorous acid is decomposed reversibly to chlorine and water. Since chlorine will be released, the acid-hypochlorite reaction can be written as follows:

$$HOCl + HCl \longrightarrow H_2O + Cl_2$$

or

$$NaOCl + HCl \longrightarrow NaOH + Cl_2$$

10.8.26 A tanker of 3500 litres capacity of acid or hypochlorite will typically take about 20 minutes to unload. The average rate of transfer of acid into the tank is approximately 175 litres/min. However, the initial rate will be much lower. As the acid is added to the hypochlorite, a rapid reaction will occur releasing chlorine gas. Assuming the transfer operation can be stopped within about 1 minute (due to chlorine detectors and shutdown), about 175litres of acid would have been added to the tank. The concentration of HCl is 31%.

10.8.27 Therefore, the amount of pure HCl added to the tank will be about = 0.31 x 175 litres x 1000g/l = 54,000 g (i.e., 54 kg).

10.8.28 From the molecular weights of pure chemicals, 36.45 kg of HCl will react with 74.45kg of NaOCl to give 70.91kg of chlorine. 54kg of pure HCl will react with 110kg of pure NaOCl to give about 105kg of chlorine. 110kg of pure NaOCl is equivalent to about 700 litres of sodium hypochlorite of 13% free chlorine. This amount of hypochlorite will be available in the tank assuming it is about half full. The amount of chlorine released within 1 minute if hypochlorite is transferred into acid tank will be much less, about 28kg only.

10.8.29 The actual release quantity is expected to be less (due to lower initial transfer rate and imperfect mixing and reaction), and therefore a release of 50kg of chlorine is considered for dispersion modelling (for the case of acid transfer into hypochlorite tank).

10.8.30 Dispersion modelling by wind tunnel tests have been carried out in a recent study on chlorine hazards [14] in addition to use of integral models and CFD (Computational Fluid Dynamics) and hazard distances to various fatality levels presented. The results for one of the sites (Au Tau Water Treatment Works) which has similar topography i.e., flat ground and few buildings in the vicinity, as the proposed Theme Park has been adopted here.

10.8.31 The hazard distance to 3% fatality (i.e., lethal dose to 3% fatality, LD03) for 50kg vapour release is approximately 250m. This distance corresponds to wind speed of 2 m/s and weather stability category D.

10.8.32 In the event that transfer operation is not stopped within one minute (based on automatic detection and operator shutdown), the maximum quantity of chlorine release is estimated as 550kg assuming 3500 litres of sodium hypochlorite solution reacting with about 1000 litres of acid. However, this quantity will be released over a duration of about 6 minutes if acid is being transferred into hypochlorite tank and in about 20 minutes if hypochlorite is being transferred into acid tank. The rate of release is therefore estimated as about 1.5kg/s and 0.5 kg/s respectively.

10.8.33 The hazard distance to 3% fatality (Lethal Dose, LD03) for continuous release rate of 1.5kg/s is given as 265m for D stability and 330m for F stability conditions. The hazard distances are similar to that obtained for instantaneous release of 50kg vapour.

10.8.34 Under either release scenario, the hotel development which is more than 600m away will not be affected. The Resort road would however, lie within the hazard range in both cases (i.e. 50kg instantaneous release and 1.5kg/s continuous release). The probability of wind blowing towards the road is assumed as about 50%. The estimation of number of fatalities is given in *Section 9.3* in *Annex I*.

10.9 RISK SUMMATION AND RISK RESULTS

10.9.1 Risk summation combines the estimates of the consequences of an event (in terms of number of fatalities) with the event frequency to give an estimate of the resulting risk, i.e. the frequency of varying levels of fatalities.

10.9.2 Risk results are presented in the form of Potential Loss of Life (PLL), FN curves and Individual Risk. The results are evaluated separately for Theme Park visitors and public off-site who include hotel occupants and road users.

10.9.3 The risk results have been derived for the following hazard events. Other hazardous events have been considered in the Study but they do not have potential to cause fatality either due to adequate safety separation distances or due to operations being carried out in the night.

Theme Park visitors

- fireworks shell landing and/or bursting near spectators within Theme Park.

(14) ERM-Hong Kong, Reassessment of Chlorine Hazards for Eight Existing Water Treatment Works, WSD

Public off-site (i.e. road users and/or hotel occupants)

- fireworks shell landing and/or bursting on road affecting road users;
- fire events during fireworks transport affecting road users;
- fire events during fireworks transport affecting hotel occupants;
- explosion events during fireworks transport affecting hotel occupants;
- chlorine release due to accidental mixing of acid and hypochlorite affecting road users.

SOCIETAL RISK RESULTS

10.9.4 The FN curves are shown in *Figure 10.8a*.

10.9.5 The FN curve for all the individual outcome events lie within the ‘acceptable’ region of Hong Kong Risk Guidelines

10.9.6 The overall FN curve for all outcome events considering both fatalities to pubic off-site and Theme Park visitors also lies in the ‘acceptable’ region.

10.9.7 The PLL values for the above cases are summarised in *Table 10.9a*. The details are provided in *Section 11* in *Annex I*.

Table 10.9a - PLL Results

Persons at Risk	Events	PLL (per year)	Contribution
Theme Park Visitors	a1) Fireworks shell affecting visitors	1.3×10^{-6}	24%
Public off-site	a2) Fireworks shell affecting road users	4.8×10^{-7}	9%
	b1) Fire events during fireworks transport affecting road users	1×10^{-6}	20%
	b2) Fire events during fireworks transport affecting hotel occupants	2.2×10^{-7}	4%
	b3) Explosion events during fireworks transport affecting hotel occupants	7×10^{-7}	14%
	c) Chlorine release due to accidental mixing of acid and hypochlorite affecting road users	1.5×10^{-6}	29%
	Overall PLL for public off-site	3.9×10^{-6}	76%
Both Theme Park visitors and off-site public	Overall PLL due to all of the above	5.2×10^{-6}	

INDIVIDUAL RISK RESULTS

10.9.8 Individual Risk is generally estimated for an hypothetical individual present 100% of the time. This approach is considered to be valid for residential developments adjoining say, a Potentially Hazardous Installation (PHI). For the present development, the persons at risk both within the Theme Park and outside the Theme Park, the Theme Park visitors, road users, hotel occupants etc. are transient population. In order to estimate Individual Risk, it is necessary to consider the most exposed individual.

10.9.9 The Theme Park visitors are expected to visit the Theme Park no more than once or twice a year. However, tour guides may visit more often, say once a week. The probability of this person attending a fireworks show during a year is 0.07 (52 shows out of 730 shows in year). The probability of him being fatally injured in the event of a fireworks incident affecting spectators is 1.4×10^{-4} (one of 3 persons fatally injured amongst 21000 visitors). The overall probability of the most exposed visitor being fatally injured given an incident is therefore 1×10^{-5}. This is multiplied with the frequency of a fatal incident to derive the Individual Risk.

10.9.10 Amongst hotel occupants, a hotel staff member (who is also considered as public) working at the south-west corner of the hotel development is assumed to be the most exposed person. However, the probability of him being present at any time is taken to be 30%. This is multiplied with the frequency of fatal incidents affecting hotel occupants and the probability of fatality.

10.9.11 Amongst road users, a regular road user such as a taxi driver who makes on average 4 journeys per day along the affected route is considered as the most exposed individual. The probability of this individual being present at the time of an incident is derived as 2×10^{-4} (4 journeys in 20,000 vehicle journeys along the road). This is multiplied with the frequency of fatal incidents affecting road users and the probability of fatality.

10.9.12 The IR results are presented *in Table 10.9b*. It is found that the Individual Risk for the road user, Theme Park visitor and the hotel occupant are lower than the IR guidelines (1×10^{-5} per year).

Table 10.9b - Individual Risk (IR) Results

Events	Event outcome frequency (/yr)	Individual presence probability	Probability of fatality[a]	IR (per year)
Theme Park visitors				
a1) Fireworks shell affecting visitors	3.2×10^{-7} 3.1×10^{-5}	0.07 0.07	1.4×10^{-4}[b] 2.4×10^{-5}[c]	3.2×10^{-12} 5.3×10^{-11}
Off-site Public				
a2) Fireworks shell affecting road users	4×10^{-7}	2×10^{-4}	0.5	4×10^{-11}
b1) Fire events during fireworks transport affecting road users	6.3×10^{-7}	2×10^{-4}	1	1.3×10^{-10}
b2) Fire events during fireworks transport affecting hotel occupants	1.3×10^{-7}	0.3	6×10^{-4}[d]	2.3×10^{-11}
b3) Explosion events during fireworks transport affecting hotel occupants	1.3×10^{-8}	0.3	0.04[d]	1.6×10^{-10}
c) Chlorine release due to accidental mixing of acid and hypochlorite affecting road users	1.5×10^{-6}	2×10^{-4}	0.1	3×10^{-11}

(a) The highest value for probability value is considered.
(b) Due to shell burst
(c) Due to impact injury
(d) The number of persons at the hotel site in south-west corner is estimated as about 1500 based on 200m by 300m area and population density of 2.6 persons per $100m^2$. The fireball event results in one fatality while the explosion event results in about 50 fatalities.

10.10 RISK MITIGATION AND COST-BENEFIT ANALYSIS

10.10.1 Although the societal risks lie in the ‘acceptable’ region, further risk reduction may be achieved by implementing additional measures. The following paragraphs consider various candidate risk mitigation measures for the hazard events identified in this Study. The Theme Park Operator may consider implementing these measures as appropriate.

RISK MITIGATION AGAINST FIREWORKS SHELL AFFECTING THEME PARK VISITORS

10.10.2 This event contributes to about 24% of the overall PLL. The main mitigation measures include the following:

(a) Increase separation distances from the firing site to spectators. Ideally, separation distances should exceed the maximum range for aerial shells (i.e. about 211 m, see *Table I7b* in *Annex I*). It is recognised that this may not be fully achievable since it will restrict the area available for Theme Park attractions (as it will require an additional separation of about 103 m over the proposed 107 m). However, it should be examined during detail design to provide separation distance as large as reasonably practicable;

(b) Optimise fence design (i.e. fence height, fence location with respect to mortars and spectators and physical configuration) to contain shell trajectory at all mortar angles (due to accidental disruption of mortars) that could potentially reach the spectator area.

RISK MITIGATION AGAINST FIREWORKS SHELL AFFECTING ROAD USERS

10.10.3 This event contributes about 9% of the overall PLL. This can be mitigated further by adopting the following measures:

(c) Increase separation distance from firing site to road (see (a) above);

(d) Partial cover above the road section (Resort Road) in the vicinity of the firing area to stop shells from falling on the road;

(e) Install road warning signs on Resort Road to warn road users about potential fireworks debris/unfired items landing on road during a fireworks display;

(f) Employ a survey team to survey the roads (East Resort and West Resort Roads) during and immediately after the show to identify any "dud" shell (i.e., unfired item) that may have landed on the road;

(g) Ensure that road users/others do not stop along the road to watch fireworks display;

(h) Impose low speed limits (on East and West Resort Roads) to enable road users to take evasive action and thereby avoid running over 'dud' shells. This also requires that adequate lighting is provided along the road;

(i) Close the Resort Road during fireworks display and until a survey team has surveyed the road for 'dud shells' (i.e., unfired item) immediately after the display.

RISK MITIGATION AGAINST FIRE EVENTS DURING FIREWORKS TRANSPORT AFFECTING ROAD USERS

10.10.4 This event contributes to about 20% of the PLL. The risk is due to thermal radiation effects from fireball events affecting passengers in passing vehicles. The results are conservative since the number of road users during night time is expected to be lower than the value assumed. Also, the road from the landing site to the Resort Road will have fewer road users than assumed for the Resort Road. The potential mitigation measure against such incidents are as follows:

(j) The driver should be suitably qualified and trained;

(k) Close the Resort Road to public during fireworks delivery.

RISK MITIGATION AGAINST FIRE AND EXPLOSION EVENTS DURING FIREWORKS TRANSPORT AFFECTING HOTEL RESIDENTS

10.10.5 This event contributes to about 18% of the overall PLL, 14% due to explosion events and 4% due to fireball events. The explosion event also has the potential to cause the maximum number of fatalities (54 fatalities) amongst all events. It has been assumed that the hotel building will be located 22m from the road and therefore is found to lie within the building damage radii given in *Table 10.8b*. However, it is noted that the assessment is conservative as some blast protection will be provided by the berm. Potential mitigation measures include :

(l) The distance from the road (the road from the landing site to the Resort Road) to the hotel building (at the south west corner of the development) should be increased as far as practicable;

(m) The window area towards the road should be minimised as far as practicable and where provided, should use toughened glass;

(n) Structures vulnerable to blast fragmentation such as a wall, trees etc. between the road and the hotel building should be avoided as far as practicable to minimise the potential for missile generation;

(o) Large congregation areas in the hotel development site towards the road should be avoided as far as practicable;

(p) Tolerant uses, such as utility area, with no windows may be located towards the road;

(q) The road adjoining the hotel development (i.e. from landing site to Resort Road) to be designed as 'works' road, i.e. used only for transport of goods to the Theme Park and not a public road. This will reduce the potential for road accidents due to other road vehicles.

(r) Reduce transport load (i.e., from 4 te NEQ to say, 2te). Although this will increase the frequency of delivery (and therefore the frequency of incident), the damage potential will be reduced.

RISK MITIGATION AGAINST CHLORINE RELEASE

10.10.6 This event contributes 29% of the overall PLL. The estimation of frequency of this event is based on gross human error probabilities and on an assumption of "high quality performance shaping factors". These cover mainly procedural and design measures, which have been identified in *Section 10.4.51 and Section 10.7.41*. The important point to make is that design and operation should conform to best practice in design and safety management, given the human error modes identified.

10.10.7 Further risk mitigation measures are identified as below:

(s) Use of dual tanks and development of procedures to ensure that the road tanker is unloaded only into a near empty tank. This will reduce the potential for chlorine release even if accidental mixing occurs. However, there is still the potential for operator error in unloading into a full tank;

(t) Install a shutdown valve on the unloading line (on the tank side) with provision for automatic shutdown by chlorine gas detectors;

(u) Reduction in number of deliveries. This will require an increase in storage quantity. Storage of hypochlorite for prolonged time periods however, results in decomposition and loss of strength over time and may not be desirable and therefore not considered further;

(v) Optimise usage of sodium hypochlorite and acids such that water quality objectives can be met by minimum dosage;

(w) Optimise location of sodium hypochlorite store and acid store with a view to maximise separation distances to public areas (see *Section 10.8.31* and *10.8.33* on hazard distances).

COST-BENEFIT ANALYSIS

10.10.8 While the previous section has identified candidate mitigation measures, a simple cost-benefit analysis is presented in the following paragraphs to examine if any of the measures would be cost-effective.

10.10.9 The maximum justifiable spend (which provides the maximum expenditure on risk reduction assuming 100% reduction is achieved) is estimated as follows:

Maximum spend = PLL x value-of-life x aversion actor x design life

10.10.10 A value of statistical life (VOSL) of HK$33 million and an aversion factor of one are considered since the FN curve is in the ‘acceptable’ region of Risk Guidelines. The design life is assumed as 50 years. The results are presented in *Table 10.10a*.

Table 10.10a - Maximum Justifiable Spend

Persons at Risk	Events	PLL (per year)	Maximum spend (HK$)
Theme Park Visitors	a1) Fireworks shell affecting visitors	1.3×10^{-6}	2,095
Public off-site	a2) Fireworks shell affecting road users	4.8×10^{-7}	797
	b1) Fire events during fireworks transport affecting road users	1×10^{-6}	1,684
	b2) Fire events during fireworks transport affecting hotel occupants	2.2×10^{-7}	365
	b3) Explosion events during fireworks transport affecting hotel occupants	7×10^{-7}	1,158
	c) Chlorine release due to accidental mixing of acid and hypochlorite affecting road users	1.5×10^{-6}	2,475
	Overall PLL for public off-site	3.9×10^{-6}	6,479
Both Theme Park visitors and off-site public	Overall PLL due to all of the above	5.2×10^{-6}	8,574

10.10.11 The maximum justifiable (one-off) spend for 100% risk reduction is only HK$ 8,574. Any mitigation measure involving an initial investment of more than this value would not be justifiable on cost grounds alone.

10.10.12Most of the mitigation measures discussed in *Section 10.10.2 to 10.10.7* are unlikely to be cost-effective with the following exceptions which may have minimum additional cost if incorporated at the detail design stage. These include (a), (b), (c), (e), (h), (i), (j), (k), (l), (m), (n), (o), (p), (q), (v), (w).

10.10.13Certain mitigation measures such as (d), (i), (k) could totally eliminate the risks from fireworks and sodium hypochlorite.

10.10.14The Theme Park Operator should examine whether any of the procedural and design measures discussed above can be adopted at minimal cost.

10.11 CONCLUSIONS

10.11.1The Hazard to Life assessment due to dangerous goods handled by the Theme Park were evaluated. The dangerous goods requiring assessment comprise fireworks and sodium hypochlorite.

10.11.2The study has considered only events with potential for causing fatality and has quantitatively assessed such risks for both Theme park visitors and public off-site. The study does not include any quantitative risk analysis of events with potential to cause injuries.

10.11.3The societal risks (of fatality) due to fireworks and sodium hypochlorite storage, transport and use were found to lie in the ‘acceptable’ region of the Hong Kong Risk Guidelines. The Individual Risk (of fatality) for off-site public and Theme Park visitors is also acceptable.

10.11.4A number of candidate mitigation measures were still examined to reduce risks to As Low As Reasonably Practicable (ALARP) but several measures are unlikely to be cost-effective. However, many measures have minimal additional direct costs provided they are incorporated at the detail design stage. Certain mitigation measures could totally eliminate the risks from fireworks and sodium hypochlorite. The Theme Park Operator should examine these mitigation measures during detail design and prior to commencing operations as part of good engineering and operating practices.

10.11.5It is therefore concluded that the risks to life due to the operation of the Theme Park and associated developments are acceptable, provided the design and operating safety measures assumed for the base case analysis are adopted. These are summarised in the sections on Impact Summary and the Implementation Schedule for the Project. The action items recommended in the HAZOP study is also summarised in the Impact Summary and Implementation Schedule.

10.11.6It is to be noted that the analysis is based on indicative locations for fireworks and sodium hypochlorite storage areas and firing sites within the Theme Park. It is recommended that an optimisation study be carried out during detail design to achieve the required safety separation distances and also examine the possibility of providing further separation distances (from public areas) where feasible and practicable.

10.12 IMPACT SUMMARY

10.12.1A summary of impacts due to dangerous goods (fireworks and sodium hypochlorite) incidents resulting in loss of life is included in the following table. The impacts will arise only during the operational phase of the Project. There will be no impacts during the construction phase as dangerous goods (fireworks and sodium hypochlorite) will not be handled.

Table 10.12a - Impact Summary

Issue	Operational Impact
Assessment Points	• Visitors within the Theme Park including Theme Park attractions and RD&E • Resort Road users • Occupants in the hotel development
Relevant Criteria	Societal and Individual Risk Guidelines in Annex 4 of EIAO TM
Potential Impacts	***Fireworks*** • Fireworks shell landing and/or bursting near spectators within the Theme Park with potential to cause fatality; • Fireworks shell landing and/or bursting on Resort Road with potential to cause fatality to road users; • Fire events during fireworks transport with potential to cause fatality to road users; • Fire and explosion events during fireworks transport with potential to cause fatality to hotel occupants in the south-west corner of the Theme park development. ***Sodium hypochlorite*** • Chlorine release due to accidental mixing of acid and hypochlorite with potential to cause fatality to road (Resort Road) users.
Mitigation Measures	***Fireworks***
	1. The fireworks store will be constructed in accordance with the requirements specified in the Dangerous Goods Regulations, CAP 295 and any additional requirements as specified by the Commissioner of Mines and the Director of Fire Services. Such requirements include for example, separation distance of 101m to spectator areas within the Theme Park, 101m to buildings and high occupancy sites outside the Theme Park and 50m to public roads and low occupancy areas outside the Theme Park.
	2. The fireworks display including mid-level shows, low-level shows and stage shows will be designed and conducted in accordance with the requirements of NFPA 1123 and 1126. This will include for example, separation distance of 107m from the firing site (for mid-level show) to public areas (both Theme Park visitors and off-site public) and separation distance of 214m from the firing site to other dangerous goods stores. Any additional requirements on fireworks display as specified by the Secretary of Home Affairs, Fire Services Department, Commissioner of the Television and Entertainment Licensing Authority will also be adopted.
	3. The fireworks will be received at the Theme Park only during night time when the park is closed to the public.
	4 A chain link fence will be installed around the firing site as a ballistic barricade to catch and deflect low trajectory shells (typically less than 15 degrees from horizontal and which have potential to burst near spectators under normal burst times) fired from a disrupted mortar such that they cannot travel towards spectators or members of the public.
	5. The launch system (for mid-level display) will be designed such that mortars will remain in upright position following the failure of any given mortar or even otherwise.
	6. Identify agencies to be contacted and establish mechanisms for reporting incidents of non-recoverable load in the event of load fall into sea while unloading at the jetty.
	7. Mobile phones, walkie-talkies should not be carried by persons handling fireworks.
	8. Fireworks store should be kept closed during fireworks display.
	9. Ensure igniters are not stored with the bulk of fireworks/pyrotechnics.
	10. The site for manipulation of fireworks need to be identified. The site shall be located at adequate safety distance from the store and public areas.
	11. 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.
	12. If vehicles such as fork lift trucks are used for transfer of goods from store to pre-rigging area or display site, it should meet appropriate specifications.
	13. The maximum height of typical 4" and 5" shells could be 150 m and 175 m respectively. The 4" and 5" shells for this display site should be designed specifically to meet performance requirements (i.e., maximum burst height of 100m).

Issue	Operational Impact
	14. Disney's vendor supply of 4" and 5" shells must ensure items destined for other Disney locations are not delivered by error to this site unless conforming to requirements of this site.
	15. Procedures to be developed if trailers are to be used for mortar installation.
	16. Any mechanical system designed for varying mortar orientation should be such that it does not result in mortars orientated towards spectators.
	17. Use of permanently installed mortars or other similar or safer alternatives to be considered.
	18. Design and position of fence to ensure containment of low trajectory shells towards spectators as well as road (off-site).
	19. The weather conditions under which fireworks display need to be moderated should be identified in procedures based on site layout and weather data. The procedures should also identify persons responsible for making such decisions.
	20. Procedures for safe handling and disposal of unfired and misfired items to be developed.
	21. Procedures to be established for sweeping site after display.
	22. Separation distances as specified in NFPA 1123 and 1126 for 'other fireworks items' (i.e., other than aerial shells) used for mid-level, low-level and stage shows will be adopted.
	23. Members of the audience will not be invited on stage during the course of discharge of fireworks or pyrotechnics.
	24. An optimisation study will be carried out during design to achieve the required safety distances and also examine the possibility of providing further separation distances from public areas where feasible and practicable.
	25. Quality control measures to ensure that offspec. fireworks items are not received/used at displays/shows.
	Sodium Hypochlorite
	26. Storage tanks for sodium hypochlorite and hydrochloric acid will be built in separate areas of the Theme Park to avoid any interaction effects between the two chemicals. There will be no piping or other interconnection between the two systems.
	27. The tanks, connecting hoses and tanker contents for both hypochlorite and acid will be clearly labelled. This will include appropriate colour coding of the tanks and connecting hoses, danger signs and safety notices. Also, the labels will be such that it is clearly visible to the delivery personnel.
	28. Clear procedural controls for tank filling and unloading will be developed. This will include clear role and responsibility description of the contractor and work site personnel.
	29. 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 work site personnel will be present throughout the unloading operation and until it is completed and the tanker leaves the tank area.
	30. The chemical suppliers Safety Management System will be assessed and audited periodically by the Theme Park Operator to ensure that procedures for supply are adequate and are being followed.
	31. The pH of hypochlorite solution will be at least 11. Acid pH will be around 3 or less. Operating procedures will include checking of pH of tanker contents by site personnel before it is transferred into the storage tank.
	32. Training will be provided to the staff in-charge of unloading operation. Clear competency specifications will be outlined for the personnel.
	33. Acid or hypochlorite will be received at the Theme park only during night time when the Park is closed to the public.
	34. Since deliveries will be made during the night, adequate lighting will be provided for proper identification of the labels on the storage tank and the road tanker and also for identification of road signs leading to the appropriate storage area.
	35. The hypochlorite and acid tanks will be located in a fenced area with a locked gate. The loading point for both the tanks will also be secured such that tanker driver cannot start unloading without authorisation and presence of site personnel.
	36. Vent/overflow line from the hypochlorite and acid tanks will be visible from the off-loading point to the operator/driver.
	37. The hose connections will be designed specifically for acid and hypochlorite unloading (such as type and size of coupling and size of hose) such that an acid tanker cannot be connected to the hypochlorite unloading point and similarly, a hypochlorite tanker cannot be connected to the acid unloading point.

Issue	Operational Impact
	38. Chlorine gas detectors will be installed around the hypochlorite and acid tank and near the tank vent with alarm annunciation at the tank area and in the central control centre or other appropriate manned location within the Theme Park. Operator will stop transfer operations immediately upon receiving alarm.
Residual Impacts	Acceptable
Environmental Acceptability	Acceptable
Further Risk Mitigation Measures	This is to be considered by HKITP operator during detailed design. It should be noted that some of these recommendations may be redundant.
	Fireworks
	39. Increase separation distances from the firing site to spectators. Ideally, separation distances should exceed the maximum range for aerial shells
	40. Optimise fence design (i.e. fence height, fence location with respect to mortars and spectators and physical configuration) to contain shell trajectory at all mortar angles (due to accidental disruption of mortars) that could potentially reach the spectator area.
	41. Increase separation distances from the firing site to road.
	42. Partial cover above the road section (Resort Road) in the vicinity of the firing area to stop shells from falling on the road.
	43. Install road warning signs on Resort Road to warn road users about potential fireworks debris/unfired items landing on road during a fireworks display.
	44. Employ a survey team to survey the roads (East Resort and West Resort Roads) during and immediately after the show to identify any “dud” shell (i.e., unfired item) that may have landed on the road.
	45. Ensure that road users/others do not stop along the road to watch fireworks display
	46. Impose low speed limits (on East and West Resort Roads) to enable road users to take evasive action and thereby avoid running over ‘dud’ shells. This also requires that adequate lighting is provided along the road
	47. Close the Resort Road during fireworks display and until a survey team has surveyed the road for ‘dud shells’ (i.e., unfired item) immediately after the display
	48. The driver transporting the fireworks should be suitably qualified and trained.
	49. Close the Resort road to public during fireworks delivery. .
	50. The distance from the road (the road from the landing site to the Resort Road) to the hotel building (at the south west corner of the development) should be increased as far as practicable
	51. The window area towards the road should be minimised as far as practicable and where provided, should use toughened glass.
	52. Structures vulnerable to blast fragmentation such as a wall, trees etc. between the road and the hotel building should be avoided as far as practicable to minimise the potential for missile generation.
	53. Large congregation areas in the hotel development site towards the road should be avoided as far as practicable..
	54. Tolerant uses such as utility areas, with no windows may be located towards the road…
	55. The road adjoining the hotel development (i.e. from landing site to Resort Road) to be designed as ‘works’ road, i.e. used only for transport of goods to the Theme Park and not a public road. This will reduce the potential for road accidents due to other road vehicles.
	56. Reduce transport load (i.e., from 4 te NEQ to say, 2te). Although this will increase the frequency of delivery (and therefore the frequency of incident), the damage potential will be reduced.
	Sodium Hypochlorite
	57. Use of dual tanks and development of procedures to ensure that the road tanker is unloaded only into a near empty tank. This will reduce the potential for chlorine release even if accidental mixing occurs. However, there is still the potential for operator error in unloading into a full tank
	58. Install a shutdown valve on the unloading line (on the tank side) with provision for automatic shutdown by chlorine gas detectors

Issue	Operational Impact	
	59.	Reduction in number of deliveries. This will require an increase in storage quantity. Storage of hypochlorite for prolonged time periods however, results in decomposition and loss of strength over time and may not be desirable and therefore not considered further.
	60.	Optimise usage of sodium hypochlorite such that water quality objectives can be met by minimum dosage.
	61.	Optimise location of sodium hypochlorite store and acid store with a view to maximise separation distances to public areas.