Australasian Fire Authorities Council

Fire Safety Guidelines for Road Tunnels

Prepared by:
AFAC – Tunnel Fire Safety Issues Committee

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EXECUTIVE SUMMARY

These guidelines have been produced by AFAC in consultation with some external bodies. A number of relevant fire safety issues and considerations have been included as part of this document which has been designed to provide information and guidelines to those fire brigades who may be involved in providing comment or requirements to Tunnel Developers.

The following is a list of the fire safety issues and recommendations made within this document:

- **Tunnel Definition**
  
  There is a distinct relationship between tunnel length and risk. As a result, the Fire Services recommend that by considering the level of hindrance to emergency operations, a tunnel can be considered long if:

  - Evacuees have no line of sight to a portal/obvious means of escape.
  - Fire products are likely to come into contact with tunnel users during evacuation.
  - Fire fighting is likely to take place after conditions become untenable.
  - The fire brigade control point is beyond the maximum useful penetration distance of a breathing apparatus set.

- **Design Fires**
  
  The tunnel structure and systems need to be designed to resist, control, suppress and remove the heat, toxic gases, and smoke produced from a fire. It is considered important then to choose a number of design fires and hence, fire scenarios that are likely to occur in road tunnels. It is recommended that in developing design fires, consideration should be made to parameters included within these guidelines.

- **Risk Analysis**
  
  A risk assessment must be conducted prior to tunnel design. Results obtained from a risk assessment must then be carefully analysed, as it is then required that a level of risk is adopted. Although risk cannot be totally eliminated and only mitigated, the Fire Services recommend that the following objectives be considered when accepting a level of risk:

  - Life safety of motorists, other occupants and emergency services personnel
• Allow the facilitation of the emergency services personnel to undertake emergency response activities
• Limit impact on property, business interruption and environmental effects.

- **Fire Models**
  For design purposes, it is recommended that the proposed fire safety strategies be assessed in terms of time to untenable conditions versus evacuation times by the use of appropriate fire and evacuation modelling techniques. Caution should, however, be taken with such modelling and it is always good practice to fully understand the limitations of the input data as well as the model itself. In addition, fire modelling results should also be compared and used in conjunction with results published from real fire tests and incidents.

- **Fire Incident Detection Systems**
  There is an absolute necessity to detect immediately any emergency incident in a tunnel that may affect the safety of the occupants.

  The fire detection system must be able to detect the fire very early in its development and also accurately locate the position of the fire. The degree of accuracy depends on the type of active fire safety systems that may be installed in the tunnel.

- **Fire Suppression**
  AFAC strongly advocates the installation of suitably designed, manually controlled deluge/sprinkler systems.

  It is considered that suppression systems will, if designed to the specific characteristics of the tunnel, control a growing fire, allowing safe evacuation, giving firefighters the opportunity to get close to the seat of the fire and hence provide an opportunity for control and extinguishment. Subject to activation, the system will also minimise the adverse effects of fire within the tunnel, providing more time for motorists to evacuate, maintain structural protection and lessen the risk of prolonged business interruption due to spread of fire.

- **Smoke Management**
  A smoke management system shall be adopted and designed to minimise the impact of smoke upon occupants and emergency services personnel.

  The main criterion for smoke management is to provide tenable conditions within the tunnel for the time required by motorists to evacuate to a safe area. The smoke management system should also provide suitable conditions for emergency services to enter the tunnel, assist with the evacuation, rescue of motorists and to initiate fire fighting strategies.

- **Communications**
  Communication facilities are installed within tunnels for the purpose of both internal and external information sharing. Due to the complex nature of tunnels and various users and operators, communications facilities are of paramount importance.

  Tunnel communications should be designed to allow the cross communication of other facilities such as information from the motorists, smoke/fire detection systems, traffic incident detection systems back to the tunnel operator and liaison between emergency personnel and/or tunnel users with tunnel operators.

  Communication facilities within a tunnel must be provided with a high level of reliability and redundancy.

- **Emergency Management**
  Tunnels pose particular problems in combating emergencies; the recent incidents in the Tauern and the Mont Blanc tunnels have highlighted the consequences of not incorporating
appropriate fire and emergency management into tunnel procedures and ensuring their continual review and upgrade.

The early involvement of tunnel operators and the fire services in the design of the tunnel’s fire and life safety features and emergency procedures will ensure that the final structure will comply with accepted building requirements or engineered principles.

- **Egress**

Egress provisions are installed within tunnels to provide a means by which occupants within the tunnel are able to evacuate the tunnel or are able to move to a location where they will be safe until they are rescued. Egress provisions are also utilised in emergencies by emergency service teams, which need to enter the tunnel to carry out emergency and rescue works.

It is not possible to provide a general recommendation for the distance between egress points and such details should be developed for each individual case after consideration of the conditions within the tunnel. However, in determining the required safe egress points for a particular tunnel, the guidelines have identified a number of critical issues that should be addressed.
Fire Safety Testing & Commissioning

The commissioning of a tunnel’s safety systems is dictated by the nature of the systems installed in the tunnel. It is usual that all systems would be individually commissioned and then commissioned in a way that would simulate the relevant scenarios and sequence of events that would be expected to take place in an ‘incident’. In other words the interfacing of the systems needs to be addressed to demonstrate that they are all working together and talking to each other.

A comprehensive commissioning process needs to be designed so that all likely and some unlikely combinations of events are examined.

Most major disasters can be attributed to a sequence of malfunctions that were not envisaged. As a result AFAC recommends the use of hot smoke tests or real fire tests to form part of the tunnel commissioning process.

Fire Fighting Equipment

It is recommended that hydrants, hosereels and extinguishers are strategically located within the tunnel and in associated buildings, and be accessible to motorists as well as staff and emergency services personnel.

Community Education

It is very important to establish communication between tunnel operators, emergency services and the public on the use of tunnels, emergency procedures, and tunnel familiarisation. It is recommended that a community education program be set up and implemented prior to the opening of the tunnels and an ongoing program be established once tunnels have been opened for public use.

Fire Safety System Maintenance

In terms of the ongoing management of tunnel maintenance of the fire safety systems, an appropriate maintenance schedule and strategy is required.

Fire Brigades must remain involved in the ongoing maintenance and review of procedures for emergency response to tunnel emergencies and liaison with tunnel operators and control rooms.

Fire Resistance

The fire resistance of a structure can be defined as the time from which the fire starts to the time when the structure can no longer serve its purpose, due to unacceptable deformation or collapse.

In the event of a fire within the tunnel, the structure and safety equipment should not burn and produce large amounts of toxic gases and smoke. The tunnel structure must not collapse and safety equipment should continue to operate while fire fighting and evacuation is taking place.

Water Supply

The method and quantity will depend upon the firefighting provisions proposed for the tunnel. Nevertheless, a reliable water supply is vital (Australian Standard 2118.1 Grade 1), such that an incident at any section within the tunnel does not delete the supply of water.

Consideration should be made for tank storage or mains tapping from both ends of the tunnel, each tapping sufficient to provide the required water quantity. In addition consideration should be made for isolation of parts of the water main for both emergency purposes as well as maintenance purposes. Isolated areas at any one time should be minimised and managed accordingly.
- **Power Supply**

  As with water supply, a reliable power supply is vital with multiple redundancies and back-up systems is recommended. Infrastructure throughout the tunnel should be protected from incidents within the tunnel such that an incident within the tunnel cannot destroy power supply for emergency situations. The use of fire rated cabling is also required to be considered for use when infrastructure protection cannot be provided.

- **Environmental Compliance**

  A drainage system should be provided in tunnels to collect, store, or discharge, or any combination of these functions, effluent emanating from within the tunnel. In addition to water discharged from the fire protection system and liquids from accidental spills, this effluent also might include water from tunnel cleaning operations and water from incidental seepage.

- **Dangerous Goods**

  Tunnels, due to their limited access and egress pose unique fire safety challenges, particularly on firefighting due to both restricted access to the fire site and the confined nature of the tunnel. With the inclusion of dangerous goods within tunnels, fire safety issues are greatly intensified.

  In addition the hazards and risks associated with the transportation of dangerous goods should be considered in light of the systems and procedures which may be adopted to mitigate such risks. There will be some forms of dangerous goods in which no single system or procedure may be utilised to handle an incident and therefore these types of dangerous goods may be totally prohibited from the tunnel if an alternative is available or the risk of such an incident is taken and therefore the substance be allowed.

  It should be noted that legislation for the transportation of Dangerous Goods in each State and Territory exists. The relevant Authority should be involved in the decision to allow dangerous goods to be taken through tunnels. In addition the transportation of dangerous goods should be addressed considering both placarded and unplacarded levels.
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1.0 INTRODUCTION

With the ever increasing construction of roadway tunnels in Australia, the Australasian Fire Authorities Council (AFAC), facilitated the development of this document through the efforts and experience of numerous Fire Brigade Personnel and external bodies. This team constituted AFAC’s Tunnel Fire Safety Committee, which has put together a guideline discussing the main issues associated with fire safety in Tunnels.

It is understood that either through legislation or the choice of tunnel developers, Fire Brigade comment is usually sought. This document has been designed to assist Fire Brigades in providing comment to Tunnel Developers regarding fire and life safety.

The use and application of these guidelines are for the purpose of providing a benchmark, however due to the fact that tunnel technology is fast developing, fire services should be open to alternative strategies to those contained within this document.

Although the issue of life and fire safety is of first priority, simple, cost effective designs should also be sought and achieved.

2.0 TUNNEL DEFINITION

There is a distinct relationship between tunnel length and risk. Although there is no cut-off length, which differentiates between a long or short tunnel, a short tunnel can be considered to be one that “even if a major fire occurs, the tunnel does not significantly hinder emergency operations” ¹. Utilising this definition tunnels can therefore be categorised short or long and thus the fire safety strategy can then be assessed based on this underlying concept.
As a result, by considering the level of hindrance to emergency operations, a tunnel can be considered long if:

- Evacuating motorists have no line of sight to a portal or obvious means of escape.
- Significant fire products are likely to come into contact with tunnel users during the initial stages of evacuation.
- Penetration into the tunnel to fight the fire is likely to take place during the fire’s peak output phase after conditions become untenable.
- The nearest fire brigade control point that can be set up in fresh air is beyond the maximum useful penetration distance of a breathing apparatus set.

The provision of fire safety systems within a tunnel does depend on the length of the tunnel in question. For instance, the issue of smoke management is for the purpose of life safety. Natural ventilation, although may be considered effective for the dilution of pollutants in one way tunnels, cannot be totally relied upon for safety purpose in long tunnels.

PIARC² (the Permanent International Association of Road Congresses) have identified several countries which have issued guidelines to limit the adoption of natural ventilation for this reason:

- Germany: Guidelines regard tunnel lengths of 350m to 700m as safe without emergency exits and mechanical ventilation
- France: Smoke control measures are required beyond the following lengths
  - Urban: 300m
  - Non Urban: 500mm
  - Non Urban 800-1000m if traffic <2000 vehicles per day per direction
- United Kingdom: Up to 400m but requires justification
- Netherlands: decided by risk analysis
- USA: NFPA502 guidelines allows the use of natural ventilation for a tunnel length up to 240m

### 3.0 DESIGN FIRES

#### 3.1 Background Statement:

Although the frequency of a fire occurring in a tunnel is very small the effects could be devastating, as shown in PIARC’s Fire and Smoke control in Road Tunnels document, Table 2.3.4².

The tunnel structure and systems need to be designed to resist, control, suppress and remove the heat, toxic gases, and smoke produced from a fire. These products produced could lead to a lack of oxygen, poor visibility and other life threatening conditions. Therefore, it is important to select a design fire which will relate to the heat release rates characteristic to the tunnel specifically under consideration. The chosen design fire will impact on the design of fire safety strategies and systems including design of the tunnel structure.
Design fires are used to establish the design criteria of the tunnel and to test the appropriateness of the tunnel parameters and operations. It is important then to choose a number of design fires and hence, fire scenarios that are likely to occur in road tunnels. The design fires should consider, but not be limited to, the following parameters:

- Types of vehicles and associated loads ie private vehicles, dangerous goods, heavy loads etc.
- Length and width of the tunnel
- Number of tubes and traffic flow directions
- Number and length of zones in each tube
- Construction materials
- The operation of the tunnel
- Availability of fire fighting equipment
- Availability of equipment to detect fire and/or inform the tunnel operator
- Earliest and average arrival time of the fire brigade
- Availability of emergency exits
- Emergency capacity of the ventilation system
- Smoke removal capacity of the ventilation system
- Traffic enforcement
- Control of fire spread or extinguishment of fire resulting of extinguishing system
- Time of application of extinguishing medium.

It should be noted that the relationship between design fires with tunnel length is the most significant factor in terms of predicting tunnel conditions during emergencies. Subsequently, a credible realistic design fire is the most important criteria when selecting appropriate fire safety provisions. The relationship between design fire and tunnel length can be summarised as follows:

- Increased fire frequency due to tunnel traffic
- Potential for fires to develop without effective control
- Necessity to increase airflow in the tunnel to establish an escape route and the consequences for this action.
- Tunnel profile and gradients
3.2 **Performance Requirements**

Different design fire and fire scenarios will need to be considered and could include one or more of the following:

- Incidents with one vehicle
- Collision incidents (two or three private vehicles, private car and Dangerous Goods Vehicle (DGV), private car and passenger coach, DGV and passenger coach)
- Pool Fires. These generally will cater for incidents involving DGV’s and flowing liquid spill fires.

The proposed fire scenarios should be outlined in a report format, which includes

- Guidelines for their selection
- Description of the aim of the scenario
- Definition of the fire parameters: fuel type, growth rate, heat release rate, peak heat release rate, propensity to spread.
- Traffic situation encountered when dealing with questions about the tunnel ventilation and operation
- Guidelines for the set-up of material tests
- Specifications to be fulfilled by material, equipment and structure with regard to fire prevention strategies

It would beneficial to conduct real fire tests prior to the tunnel design, however tests that have been previously conducted may be used in designing the structure and life safety system. In either case the following information is required:

- Burning rate
- Heat release rate
- Temperatures
- Visibility readings
- Toxic emission
- Smoke production
- Activation times of fire fighting equipment (automatic and manual devices)
- Limitation and assumptions associated with the tests ie methodology, test apparatus, application, recording equipment, environmental conditions etc.

In the process of accepting a design fire, it is essential that the assessing authority consider the following:

- Has the design fire been based on a comprehensive fire hazard analysis?
- Does the design fire account for fire parameters (heat release rates, smoke production vs time, temperatures etc.)?
- Has the development of the design fire included for the probability of occurrence?
- Has the fire scenario developed for the design fire included the various phases of fire development over time? This will allow the comparison between evacuation scenarios and times to untenability.
A limited number of tests have been conducted worldwide in road, rail tunnels and opened and closed deck carparks. The tests vary in their nature and results and some, due to the ever-increasing plastic content in vehicles, new materials and various fuel loads, may have limited application. This issue highlights the need for more real and applicable fire testing of vehicles within tunnel environments. Nevertheless the following section will summarise the results of those tests identified useful for Tunnel applications:

3.2.1 BHP Fire Tests

For the purpose of developing the Australian Building Code, in terms of fire safety in carparks utilising bare steel, 3 series of fire tests from 1985-1989 were conducted by BHP Research.

The series of tests include:

- Open deck carparks
- Closed carparks
- Partially open carparks

Vehicles and building construction typical of the Australian environment were used. Basically the test consisted of multiple cars with fires being initiated in vehicles with both steel and plastic petrol tanks. A test incorporating an LPG tank was also included.

It should be noted that the cars were closely spaced and windows were left down. The test structure was filled with cars to simulate a fully loaded situation.

**Open Car Parks**

Overall the spread of fire between the vehicles took some time with eventually 3 cars being involved. It should be noted that these cars were of solid steel construction. It should be noted that today's vehicles are fitted internally and externally with much more plastic content than those tested. Overall a large quantity of dense smoke was generated, but this smoke was vented through the open sides. The test structure supported the loads throughout the tests and the temperatures showed that significant safety factors are associated with bare steel in fire conditions.

**Closed Car Parks**

The following findings were made:

- 9 tests were conducted, utilising 5 cars within the test structure with a spacing of 400-500 mm between vehicles.
- Each test, a fire was initiated in a large sedan with either a plastic or steel fuel tank.
- Tests demonstrated that without a functioning sprinkler system, fire spread to other vehicles will occur with very large quantities of dense toxic smoke being generated.
- Tests in which sprinklers operated automatically resulted in suppression of the fire, no spread to adjoining vehicles and greatly reduced volume of smoke and a significant reduction in toxicity of smoke.
- With a functioning sprinkler system, the temperature of the steel members and columns was less than 100°C

It should be noted that the report states that for the non-sprinklered case, exposure to the volume and toxicity of smoke produced would not only be life threatening to occupants, but visibility will be rapidly reduced.
**Partially open Carparks**

The series of tests conducted for partially open carparks resulted:

- Tests found that fire could spread rapidly in a partially open situation with large amounts of smoke being generated
- Partially open carparks should be treated as closed carparks.
- Significant quantity of smoke was produced from a fire test associated with a burning 60 litre plastic fuel tank

### 3.2.2 Japanese Fire Tests

A number of partially, open deck, carpark fire tests have been conducted by Japanese commercial and educational facilities. Due to their interest in increasing the number of carparking facilities through the construction of taller and larger car parks, a series of tests were conducted to examine the feasibility and safety of prefabricated multi storey car parks. The purpose of the experiments is to understand the behaviour of car combustion and structural steel framed under extreme conditions.

The following were investigated in terms of fire resistance properties:

- Investigate the premise that fires would not spread to surrounding vehicles as suggested by European Tests
- Structural frame temperatures
- Structural frame deformation
- Structural collapse

The test utilised a 4-storey structure 30 X 20m in area per floor having a storey height of 2.9 metres. Each floor contained 12 cars ranging from medium sized 4 door sedans, wagons and a van.

The cars were parked side by side in 2 rows in a corner configuration. The floor of fire origin had 2 sides of the structure closed by thermally insulated material with the remaining 2 sides fully open. A car, one from the corner, was set alight, after 8 minutes 30 seconds, fire spread to the left side car, after 19 minutes 15 seconds fire spread to the right side car, after 23 minutes 45 seconds fire spread to the tail side car. Fire spread continued to 8 cars within 43 minutes from ignition till fire-fighting activities intervened.

In terms of temperatures, the maximum temperature reached was 700°C, at a beam which was positioned immediately above the car of fire origin after 10 minutes from ignition. Then the temperature decreased for up to 20 minutes and remained at approximately 500°C till 35 minutes after ignition. Thereafter, the temperature increased until fire-fighting activities commenced at 43 minutes 45 seconds.

Conclusion made from these tests are as follows:

- Car fires spread one after the other
- The steel temperatures of a beam located above the fire areas reached maximum 700°C
- The degree of structural deformation is \( \frac{1}{4} - \frac{1}{2} \) of critical deformation but the strain enters the plastic region
- The structure does not collapse even though it is subjected to severe fire conditions.
3.2.3 PIARC Recommendations

Based on PIARC’s report presented in Brussels 1987, Eureka tests in Norway and Finland, Memorial Tunnel test in the US and CETU proposals in France, the following are approximate heat release rates and maximum temperatures that may occur for significant durations in a fire event within a tunnel:

<table>
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<th>Test Specimen</th>
<th>Heat Release Rate (MW)</th>
<th>Max. Temperature on tunnel walls (°C)</th>
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<tr>
<td>1 small passenger car</td>
<td>2.5</td>
<td>400</td>
</tr>
<tr>
<td>1 large passenger car</td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>2-3 passenger cars</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>1 van</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>1 bus</td>
<td>20</td>
<td>800</td>
</tr>
<tr>
<td>1 HGV general goods</td>
<td>20 – 30</td>
<td>1000</td>
</tr>
<tr>
<td>DGV &amp; HGV (larger vehicles)</td>
<td>100 – 120</td>
<td>1200 – 1400</td>
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HGV: Heavy goods vehicle

DGV: Dangerous Goods vehicle

For detailed information please refer to references: 2, 3, 4, 5 and 6.

It should be noted that a number of limitation and conditions are associated with these tests, for instance: The EUREKA Fire Tests have been conducted on numerous types of vehicles and the results obtained are dependent on the test conditions, which include low air velocities for most cases and slightly higher for the DGV. The figures obtained for most of the tests where over a long duration, whereas the DGV had higher values but for only a short duration.

3.2.4 Maestro and Citron Car Fires

Two full-scale car fire tests were conducted under controlled conditions in a canopy and duct configuration. The fires were well vented and allowed to fully develop before firefighting intervention.

The first of the tests was started on the seat of the Maestro. The fire spread throughout the whole interior within the first 6 minutes and after 11 minutes the whole car was involved. The test was terminated after 17 minutes as the rig was in danger of collapse. A peak temperature of 1250°C was recorded at about 13 minutes, with the lowest temperature reading being 160°C. A peak heat release rate of 7 1/2 MW was recorded before thermocouples were destroyed, but it was estimated to reach 8 1/2 MW. There was a large amount of smoke spillage from the rig.

The Citron fire was started in the engine. Flames first appeared from the edges of the bonnet after 2 minutes. Smoke began to fill the car after 4 minutes and after the fifth minute the fire spread though the whole car. The fire never became severe and smoke was contained within the hood.

Peak temperatures of 1250°C was recorded and a peak heat release rate of 4 1/2 MW was estimated.
These values were significantly less than those recorded by Mags and Keski-Rahkonen\textsuperscript{8}, 1 ½ MW and 2MW, but close to the 3MW estimated by Heselden\textsuperscript{9}.
4.0 RISK ANALYSIS

4.1 Background Statement:

Typically a risk assessment is conducted prior to tunnel design. The purpose of the analysis is to identify hazards that can occur and attributing a probability and a level of consequence. Due to the limited number of incidents, lack of uniform approaches to tunnel fire safety and insufficient databases, for the purpose of risk assessment is very limited. Further, major fires are rare events, however consequences of one fire could change the risk significantly as with the Mont Blanc and Tauern fires in which 51 deaths and 79 injuries occurred, not to mention the damage caused to the tunnels. These tunnels were closed for at least 24 months and 12 months respectively, with significant subsequent economic impacts at national and international levels.

It should be noted that ‘Tunnel Management International (TMI)’ a worldwide magazine provides a platform for information dissemination and has advised, within the February 2001 edition, that the Tunnel Incident Reporting Service (TIRS) has been developed to provide details on all major tunnel incidents. For more information TMI’s website can be visited on: http://www.itc-conferences.com.

Results obtained from a risk assessment must then be carefully analysed, as the next step is for the appropriate Authority to accept a level of risk. Although risk cannot be totally eliminated and only mitigated, the Fire Service recommends that the following objectives be considered when accepting a level of risk:

- Life safety of motorists and other occupants
- Life safety of emergency services personnel
- Allow the facilitation of the emergency services personnel to undertake emergency response activities
- Limit impact on property, business interruption and environmental effects.

A risk management approach is important in establishing reasonable design fires for the basis of engineering analysis and fire safety strategy development.

4.2 Frequency of fires

Vehicles travelling in the tunnel are the main concern when considering road tunnel fires. These fires are generally caused by electrical defects, overheating of brakes and other vehicle defects. Statistics show less frequent causes of fires are collisions, mechanical defects and maintenance work in the tunnels.

The frequencies of the fires don’t generally relate to the magnitude of the fire but do relate to tunnel characteristics ie. the length of the tunnel, traffic density, speed control, etc. Therefore the frequencies of fires relate to the number of vehicles passing through the tunnel and the length of the tunnel.

PIARC has documented the number of occurrences and fire rates for 45 tunnels (refer to Tables 2.3.1 and 2.3.2 within the PIARC document pgs 42-45) across the world. It should be noted that the data is limited to their observation period and one single fire could change the rates significantly. Also some data was restricted to certain tunnels.

From the above mentioned tables the following has been found:

- The average rate of fires for the tunnels is very rare (25 fires per $10^8$ vehicles x (tunnel) km).
- Urban tunnels tend to have a higher fire rate than other tunnels.
- Approximately 40% of the observed tunnels had no fires.
The rate for HGVs fires was higher than passenger cars in some of the tunnels.

The risk of a fire occurring in a tunnel tends to increase in situations where there is an increase in engine and brake heating, ie steep uphill lanes, tunnels after steep hills, long downward slopes. Also there is a higher risk for a short period of time when the tunnel is first opened. This was observed in the Elb Tunnel, where drivers were not familiar with the tunnel.

It was found, worldwide, that only very few fires develop into major fires with serious consequences for the users and operators. However a number of significant fires have occurred and it is recommended that in no circumstance fires such as these should be unaccounted for during the design stage.

The following is a summary of significant recent tunnel fires:

**Mont Blanc**

On the 24th of March 1999, a fire initiated in a truck with a thermal foam trailer containing flour and margarine. 38 people died in the tunnel and a fire chief later in hospital. Two victims were found in a refuge. The tunnel was closed for at least 2 years.

**Tunnel Characteristics:**

- 11.6 kms long
- bi-directional traffic
- vehicle rests every 300m
- Safe refuge area provided at every 2nd rest area
- 2 x fire extinguishers and manual call points every 100m
- Hydrants, telephones and call points provided every 150m for use by fire brigade personnel.

**Findings of the report:**

- The speed and magnitude of fire development within the 1st truck attributed to the spread of fire to other vehicles
- The smoke extraction was limited in capacity
- Operational manner of the ventilation system resulted in the supply of air more than exhaust, which accelerated the fire.
- A lack of communication and co-ordination between attending emergency response agencies
- Inadequate and poor functioning of equipment (tunnel closure, lights, ventilation to refuges, location of exit lighting, no central facility, lack of fire water, incompatible equipment, fresh air duct to refuge also serves a tunnel exhaust.)

**Tauern Tunnel**

At the time of the incident, which occurred on the 29th May 1999, a construction site was set up within the tunnel with signal lights regulating the traffic. The work site was confined to a single lane closure.

A truck drove into the back of stationery vehicles at high speed, pushing 4 cars under a truck stopped in front. The actual accident resulted in 8 deaths and the truck catching fire. Fire extinguishment attempts were unsuccessful, fire spread to another truck containing aerosol cans which intensified the fire. The result of this incident included 12 deaths, 49 injuries, 14 trucks, 26 cars destroyed and 3 months tunnel closure.

**Tunnel characteristics:**
6.4km long
bi – directional
emergency bays 212m apart
fire extinguishing bays 106 m apart
breakdown bays every 750 m

St Gotthard Tunnel

A fire occurred in a car transport carrying 6 vehicles on 21st October 1997. The report into the fire found:

- This was the 3rd significant fire in the tunnel
- As in previous fires, several tunnel users remained within their vehicles in spite of the conditions created by the fire
- The heat release rate was estimated to be approximately 22MW
- The existence of shelters be made better known to the motorists (more and larger escape signs, leaflets, radio communications etc.)

4.3 Risk and Safety

Generally, it is accepted that an absolute level of safety cannot be attained and therefore in conducting a risk assessment there has to be acceptance of a certain degree of risk for tunnels as there is for the remaining transport system.

As a result tunnel designers can only mitigate the increased risk associated with tunnel use rather than eliminate the risk.

The risk management approach as detailed within Australian Standard 4360 Risk Management 1995, provides a methodology by which a risk assessment may be undertaken. Although the approach within the standard is presented in a generic form, it can be easily applied to most situations.

In terms of accepting a level of risk, the UK’s Health and Safety Executive: Qualified Risk Assessment can also be used as a reference. This strategy can be utilised in risk assessment and involves the testing of the proposed safety system. The following summarises these tests:

a) Whether a given risk is so great or the outcome so unacceptable that it must be refused altogether, or;

b) Whether the risk is, or has been made, so small that no further precaution is necessary, or;

c) If risks fall between the above, whether the risk has been reduced to the lowest level practicable, bearing in mind the benefits flowing from its acceptance and taking into account the costs of any further reduction.

In order to assess the tunnel fire risk profile, a hazard analysis should be undertaken. The technique may involve the examination of each potential hazard and the method by which an incident/accident could occur is identified. Both the frequency of the hazard and the probability of the incident and the consequences are combined to categorise the risk of each accident.

The following tables, extracted from a paper written by John Day of Electrowatt Engineering Ltd, provides two tables listing tunnel fires which resulted in deaths from 1978 till 1999. Table 1 lists incidents that did not include dangerous goods, the second table listing incidents which included dangerous goods.
Table 1: Fatal tunnel fires not involving dangerous goods

<table>
<thead>
<tr>
<th>Year</th>
<th>Tunnel</th>
<th>Length</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>Velsen, Netherlands</td>
<td>770m</td>
<td>5</td>
</tr>
<tr>
<td>1983</td>
<td>Percorile, Savone, Italy</td>
<td>600m</td>
<td>8</td>
</tr>
<tr>
<td>1986</td>
<td>L’Arme, nice, France</td>
<td>1105m</td>
<td>3</td>
</tr>
<tr>
<td>1987</td>
<td>Gumefens, Bern, Switzerland</td>
<td>340m</td>
<td>2</td>
</tr>
<tr>
<td>1993</td>
<td>Serra Ripoli, Italy</td>
<td>442m</td>
<td>4</td>
</tr>
<tr>
<td>1994</td>
<td>Huguenot, South Africa</td>
<td>3914m</td>
<td>1</td>
</tr>
<tr>
<td>1995</td>
<td>Pfander, Austria</td>
<td>6719m</td>
<td>3</td>
</tr>
<tr>
<td>1999</td>
<td>Mont Blanc, France/Italy</td>
<td>11,600m</td>
<td>39</td>
</tr>
</tbody>
</table>

Table 2: Fatal tunnel fire involving dangerous goods.

<table>
<thead>
<tr>
<th>Year</th>
<th>Tunnel</th>
<th>Length</th>
<th>Deaths</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>Nihonzaka, Japan</td>
<td>2,045m</td>
<td>7</td>
<td>Collision, ether</td>
</tr>
<tr>
<td>1980</td>
<td>Kajiwara, Japan</td>
<td>740m</td>
<td>1</td>
<td>Collision, paint</td>
</tr>
<tr>
<td>1982</td>
<td>Caldecott, Oakland, USA</td>
<td>1,028m</td>
<td>7</td>
<td>Collision, benzine</td>
</tr>
<tr>
<td>1996</td>
<td>Isola delle femmine, Italy</td>
<td>148m</td>
<td>5</td>
<td>Collision, LPG, BLEVE</td>
</tr>
<tr>
<td>1999</td>
<td>Tauern, Austria</td>
<td>6,400m</td>
<td>12</td>
<td>Collision, paint/lacquer</td>
</tr>
</tbody>
</table>

5.0 FIRE MODELS

5.1 Modelling Precautions

Computer models for predicting smoke movement are necessarily complex and incorporate numerous computations derived from physics and chemistry. As with any computer model the old adage ‘Garbage in – Garbage out’ applies. The data used as input to these models, however, is only one consideration. Knowledge of the limitations of the model and the interpretation of the results are crucial to the credibility of the predictions.

It should be noted that other models for the purposes of assessing evacuation strategies and fire brigade intervention25 exist. These models are also subject to limitations and assumptions.
5.2 Input

Input data for smoke modelling must include the design fires, and some or all of the following:

- Geometry of the tunnel, e.g. cross section, gradient, curvature,
- Air movement details in normal operating mode and in smoke control mode,
- Effect of suppression systems on smoke movement,
- Effect of stationary vehicles in the tunnel after an incident that would effectively reduce the cross section of the tunnel and affect the air velocity.
- Design of pressurisation systems for pedestrian egress tunnels
- Effect of external wind.

The most important item is the design fire and it is essential that the most appropriate available data should be used.

5.3 Limitations

All computer models have limitations. Limitations can be identified by comprehensive validation and by comparison with validated models. It is important to know the limitations of the model utilised as the reliance on results that are provided will be dependant upon these limitations.

5.4 Interpretation of results

With any model, the results can be easily misinterpreted. One needs to have a feel for what the expected results should look like. Engineering judgement is a common description of the approach used, but without experience of real smoke movement and without knowledge of the model's limitations, engineering judgement can be just a good (or bad) estimate. It is always useful to compare results obtained from computer models with results obtained from real fire tests and hot smoke tests.

5.5 Result Analysis

Engineering models are utilised to produce data, which will enable the specification of mitigation systems, equipment and processes. Models used should be able to predict smoke layer depth and temperatures so as an assessment of the likely conditions experienced by evacuating occupants and emergency services.

The following fire parameters can be obtained from these models:

- Smoke layer height profile
- Temperature profiles
- Toxicity level profiles
- Radiant heat flux

The above parameters can be utilised in the assessment of:

- Ventilation requirements and sequencing
- Evacuation routes and spacing of exit/refuge points
- Appropriate signage requirements
- Communication facilities
- Suppression requirements
- Tenability times and tenable areas
5.6 **Computer tools**

Due to the limited number of fire tests and due to high costs associated with real fire tests, computer simulations are widely used.

With the availability of fast and powerful computers, simulations can be made with results validated and compared to real fire tests.

It is recognised that Computational Fluid Dynamic (CFD) filed codes are the most adequate tools available for tunnel fire modelling and simulations.

CFD techniques consist of dividing the tunnel volume into many small cells in which thermodynamic equations for velocity, temperature and smoke concentrations are solved. These models currently require very powerful computers and long duration computer running times. There are a number of codes, which have been validated for specific tunnel applications.

Zone models are not recommended for use in the study of fire in tunnels. Their application is more suited to buildings. The underlying principle of zone models is that the modelled area consists of only 2 zones where fresh air is contained in lower zone and the upper layer is the smoke zone. A plume, modelling the output from a fire, pumps hot smoke into the upper layer whilst collecting fresh air from the lower layer. Each zone is assumed to have constant characteristics throughout each individual zone.

As mentioned above, zone models are not applicable to tunnel situations, as the models are limited in their ability to deal with external forces such as longitudinal air flows. Insufficient validation of the such models and their inadequate capability to deal with environmental tunnel conditions make such models inappropriate for tunnel purposes. Nevertheless zone models may be utilised to assess the tenability conditions within short/small egress compartments.

### 6.0 FIRE INCIDENT DETECTION SYSTEM

#### 6.1 Background Statement:

There is an absolute necessity to detect, immediately any emergency incident in a tunnel that may affect the safety of the occupants and raise an alarm with the tunnel operator. There are two types of incidents that can easily become a danger to other tunnel occupants:

- fire or,
- any incident that causes vehicles or objects to become stationary within the tunnel.

The fire detection system must be able to detect the fire very early in its development and also accurately locate the position of the fire. The degree of accuracy depends on the type of active fire safety systems that may be installed in the tunnel.

Closed Circuit Television (CCTV) cameras (pan-zoom type) fitted with an incident detection system are considered to be vital, together with a fire detection system in providing early detection.

Vehicles or objects can become stationary in a tunnel due to either mechanical failure, an accident or due to falling debris from a moving vehicle. All stationary objects are considered a hazard to tunnel occupants and their presence must be signalled to the tunnel operator as soon as possible.

The incident detection system can be installed in the tunnel’s carriageway pavement or by CCTV cameras incorporating incident detection software.

Incident detection systems should incorporate the following features:

- Automatic Incident Detection System connected to CCTV. Thus allowing view locking to an area where a vehicle has stopped or slowed down and bring the location onto the operators visual screen. An audible alarm should also be automatically raised at the control room.
- Due to glare problems, cameras should be placed viewing in the direction of traffic flow.
- Heat Detection and Tracking System providing capabilities to track the growth of the fire when cameras do not have visibility.
- Fire detection system must be permanently connected with a direct data link to fire station or fire station dispatch centre.
- The detection system must be accurate enough to activate the correct deluge zone and smoke hazard management systems.
- The CCTV system should have sufficient cameras with pan, tilt and zoom facilities:
  - To enable operator to examine any part of the road surface
  - For detailed views of vehicles, camera spacings will depend on camera capabilities, however not more than 150m intervals is recommended.

In the event of a fire, smoke conditions may reduce the effectiveness and visibility through the CCTV cameras. As a result thermal imaging capabilities incorporated within the cameras should be considered as an option or locating the cameras at a height which would reduce the effect on visibility due to the smoke layer. It should be noted however that a linear heat detection system may provide an accurate location of the fire and the extent to which it has spread throughout the tunnel system.

As learned from the CityLink Hot smoke tests\(^2\), CCTV cameras were fitted with pan, tilt and zoom facilities and additional cameras were fitted such that the system had full coverage of the tunnel.
6.2 **Performance Statement:**

Suitable detection systems must be installed to the accuracy necessary in a tunnel to detect fire, stationary vehicles and objects on the vehicle carriageway appropriate to:

1. Alerting the tunnel operator; and
2. Alerting the tunnel occupants; and
3. Activate any active fire safety systems
4. Provide the location of the incident within the tunnel ie signage, identification etc.
5. Alerting the fire services

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7.0 **FIRE SUPPRESSION**

7.1 **Background Statement**

Uncontrolled fires in tunnels have disastrous effects. The Mont Blanc tunnel fire resulted in many casualties and significant problems for fire fighting personnel to control the fire. Due to the confinements of tunnels, large uncontrolled fires create many problems and it is for these reasons AFAC strongly advocates the installation of suitably designed manually controlled deluge/sprinkler systems.

It is considered that suppression systems will, if designed to the specific characteristics of the tunnel, control a growing fire, allowing safe evacuation, giving firefighters the opportunity to get close to the seat of the fire and hence provide an opportunity for control and extinguishment. Subject to activation, the system will also minimise the adverse effects of fire within the tunnel, providing more time for motorists to evacuate, maintain structural protection and lessen the risk of prolonged business interruption due to spread of fire.

Based on the Melbourne fire brigade’s experience, with the integration and proper operation of the ventilation system, the smoke produced can be controlled within the area of fire origin or dissipated to lower temperatures and toxicity levels throughout the tunnel. This result was also noted by Commonwealth Scientific Industrial Research Office (CSIRO) whereby the activation of the deluge created a wall of smoke which extended only to the last open exhaust damper, after which the smoke downstream the 2nd damper cleared within 12 minutes due to controlled ventilation conditions. It is therefore considered, that steam produced due to the operation of the deluge system will only be created within the proximity of the fire. It is expected that occupants downstream from the fire, would have driven away from the fire affected area and therefore the effect of steam and smoke will only affect those who remain in the immediate fire zone. It is considered that the environmental effect of the deluge system will be less harmful to motorists than the heat and toxic smoke produced from an uncontrolled fire.

Issues which need to be considered include:

- Installation of an appropriate suppression system (suitable for typical fire load)
- Dangerous Goods – may require foam injection
- Drainage, flame traps, storage, pumps etc.
- Tunnel floor area, ceiling height, system zones
- Water supply and reliability of water supply
- Deluge/sprinkler head
- Water quantity
- Road surface and design
It should be noted that PIARC does not recommend the installation of sprinklers for the following reasons:

- Most fires start in the motor room or in the compartment, and sprinklers are of no use until the fire is open
- Water can cause explosions in petrol and other chemical substances if not combined with appropriate additives
- There is a risk that the fire is extinguished but flammable gases are still produced and may cause an explosion
- Vaporised steam
- Smoke layer is cooled and de-stratified, so that it will cover the whole area of the tunnel
- Maintenance can be costly
- Sprinklers are difficult to handle manually
- Visibility is reduced

Nevertheless PIARC do state that sprinklers can be used to cool down vehicles, to stop the fire from spreading to other vehicles and to stop secondary fires in lining materials. PIARC also states the experience from Japan shows that sprinklers are effective in cooling down the area around the fire, so that firefighting can be more effective.

It is considered that such concerns also stem from the harsh environmental conditions ie extreme low temperatures which may cause water contained in deluge pipework to freeze, making the use of such equipment in some parts of Europe impractical.

AFAC considers that together with a manually controlled sprinkler/deluge system and the implementation of operational procedures, concerns regarding the effects of deluge operation on motorists can be addressed. In addition, Fire Services experience with steam production due to water application has never been an issue.

It should also be noted that after the Mont Blanc and Tauern tunnel incidents, there has been public pressure to increase safety in tunnels. Motoring organisation have surveyed tunnels and published results confirming that there is a real concern that current tunnel designs do not incorporate adequate fire safety provisions.

A report from the Stockholm fire brigade on tunnel and underground plant fire and rescue operations reported on a project to assist the local Swedish fire brigades in planning and executing rescue operations in tunnels. The report recommends the investigation of a combination of sprinklers and ventilation for use during fire and rescue operations. This need for investigation is also supported by the Swiss Federal Labour Inspectorate, which urges that research be intensified to better understand the potential effectiveness, practicability of sprinkler systems during road tunnel fires.

According to the Swiss Institute of Safety and Security, it considers that the installation of sprinklers within rail and road tunnels could also serve to control fires and keep temperatures inside tunnels from reaching very high levels. It also considers that sprinklers may assist in containing fires and preventing large quantities of toxic fumes. In addition, the institute stated that sprinklers would greatly increase the chance of survival of occupants as well as assisting fire fighters to reach the seat of the fire.

Please refer to the following summaries of papers dealing with various system types.

7.2 Research documentation of fixed suppression systems in tunnels
A series of Australian based tests, conducted in Melbourne in 1985-1989 by BHP research looked at vehicle fires in carparks. Tests conducted in closed carparks demonstrated that without a functioning sprinkler system, the fire would spread to other vehicles with very large quantities of dense toxic smoke being generated. In contrast, where sprinklers activated automatically the fire was suppressed, no spread occurred to adjacent vehicles and there was a great reduction of smoke and toxicity. Also the temperatures of surrounding steel members were maintained below 100°C. Where the sprinkler was operated manually the fire was rapidly controlled and temperatures, smoke and toxicity reduced. (Fire and Unprotected Steel in Closed Carparks, BHP)

The above cannot directly be applied to tunnels as other issues such as, water density, ventilation systems, tunnel dimensions, etc, will have a different effect on the fire. However with such issues considered and designed appropriately, it is envisaged that the effectiveness of sprinkler in tunnels will be similar to that achieved in carparks.

Rail Tunnel Test\textsuperscript{17} – Three pool test fire -

<table>
<thead>
<tr>
<th>Petrol Quantity (l)</th>
<th>Pool Size (m\textsuperscript{2})</th>
<th>Duration of Fire (min)</th>
<th>Burning Rate (l/m\textsuperscript{2}, min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>6.6</td>
<td>2 $\frac{1}{2}$ - 4</td>
<td>3.7, 5</td>
</tr>
<tr>
<td>500</td>
<td>47.5</td>
<td>3 – 7</td>
<td>1.5, 3.5</td>
</tr>
<tr>
<td>1000</td>
<td>95</td>
<td>12 - 14</td>
<td>0.8, 0.9</td>
</tr>
</tbody>
</table>

These results vary, due to different test preformed with each petrol quantity eg. different ventilation systems. In tests where sprinklers activated, the duration of the fire and burning rates are unknown, but the fire was extinguished within a short time and resulting in the local production of hot steam.

The report did not specify the quantity nor the test in which steam was produced.

The Swedish National Testing and Research Institute\textsuperscript{18} has undertaken research and conducted fire scenarios similar to fires expected in highway tunnels for three types of fixed fire suppression systems. These systems include foam-water sprinklers, water spray and water mist systems. Each systems covers a number of subjects ranging from the advantages and disadvantages, principles of activation, water discharge densities for fire control or suppression and water duration times. A summary of these findings on the various systems is provided herewith:

\textbf{Requirements of fixed fire suppression systems}

Based on the fire scenarios it was found that any type of system should meet the following fundamental requirements:

- An open deluge type system is more preferable compared to automatic wet-pipe or dry-pipe sprinkler systems where a large fire could activate a multiple number of sprinklers and overtax the water supply system. The deluge zones size must be based on the width of the tunnel and the water supply capacity.

- A fire detection system must be implemented and the activation of the fire suppression system should have a delay of 30 to 60 seconds to allow for the tunnel operator to verify the alarm. Numerous fire detection systems can be implemented, however smoke detectors are not appropriate for the tunnel environment.
The water supply duration and foam concentration (if used) should be based on the expected duration of the fire scenario. Safety factors should also be implemented.

Fixed fire suppression systems, such as sprinklers, do have some unfavourable conditions compared to a non-sprinklers situation. As reported in Josephson and Shafer, 1992 and Haerter, 1994 these conditions could be as follows:

- Visibility can be reduced by water spray and smoke cooling and dropping, resulting in people’s ability to evacuate. Also accidental activation of the sprinkler system could result in traffic accidents.
- Steam can result in higher temperatures and hot smoke being pushed further away from the fire.
- Water can cause flammable liquids to spread the fire and increase in size.
- Vapour explosions after the water is turned off could pose a risk.

**Foam Water Sprinklers**

**Test Description:**

The fire suppression tests undertaken were to investigate the performance of the foam-water sprinkler systems with different nozzle locations, ventilation velocities and heat release rates. Three tests where conducted with a suspended ceiling inside the tunnel and two without the ceiling in which the sprinklers were install at a height of 2.1m above the floor. A foam-water mixture of 3% AFFF was used.

**Discharge Density:**

A discharge density of 3.8mm/min was estimated for the tests conducted with a suspended ceiling and a discharge density of 2.4 mm/min without the suspended ceiling.

**Heat Release Rate:**

All test conducted with the suspended ceiling had a fire with a heat release rate of 20 MW. The two additional tests without the suspended ceiling had fires with heat release rates of 50 MW & 100 MW.

**Results:**

The longitudinal ventilation velocity of 4.2m/s had a minor impact on the performance of the foam-water deluge system. All fires were extinguished within the first 30 seconds.

When nozzles were installed along the walls, extinguishment was generally longer (2 minutes). This could have been due to non-uniformed coverage of the area, low discharge densities and higher heat release rates.

**Discussion:**

It was found that the above discharge densities may have been sufficient to suppress the liquid fires but a large scale test conducted (Arvidson, 1997) had shown higher discharge densities are required. NFPA 16 (NFPA, 1995) recommends a discharge density of 6.5mm/min.

**Water Spray Systems**

**Test Description:**

The Technical Research Centre of Finland has conducted tests on 10 different flammable liquids using 7 different types of nozzles. The results from these tests can be applied to
tunnels. The flash points of the tested liquids ranged from –6°C to 234°C and pool fire sizes form 0.4m² to 12m². Also the heights of the nozzles varied from 3m to 8m above the pool.

Results:
The water spray cooled the fuel surface below its flash point in most of the cases. Liquids with flash points greater than 60°C could be extinguished reliably, whilst the water spray was not as effective with liquids whose flash points are lower.

The application rates for fire control were greater for large pool fires than smaller pool fires.

Where sprinklers were located high above the pool surface, splattering may be unfavourable and the fire may only go out when the water is turned off.

The measurement for the capacity of the extinguishment system can not only rely on the delivered density. One of the tests showed that 7mm/min was sufficient to control a fire, whereas in another test with a different nozzle 34 mm/min was unable to control the fire. Nozzle type and size are important factors.

Discussion:
The above tests were conducted on exposed fires, fires where the water spray is obstructed is likely to required higher application rates. It was found that liquids with flash over points greater than 60°C could be controlled with a water application rate of higher than 25mm/min and 10mm/min for liquids with flash over points greater than 120°C.

Water mists systems

Test Description:
The Technical Research Centre of Finland conducted a series of tests using fire scenarios similar to those expected in highway tunnels. The systems were tested with foam-water mixture and plain water.

Results:
The higher the concentration of foam-water, the reduction in its cooling ability.

None of the fires where extinguished with the foam-water mix, however in two tests the fire was suppressed. The reigniting of fires did not occur as quickly when the system was turned off, as the foam blanketed the fuel compared to tests done without the foam.

The water pressure had an affect on the fire. Pressure effects was only tested with a water system. Fires were suppressed with 130 and 100 bar but not 80 bar. 130 bar corresponds to a discharge density of 2.3mm/min. The fires redeveloped once the system was shut off.

The simulated fright truck fire scenario was controlled but not extinguished by the system, and redeveloped once the system was shut off. Also a higher operating pressure resulted in lower temperature. A ceiling reading of 600°C was measured with the maximum pressure and 800°C and minimum pressure.

Discussion:
Water mist systems have a long extinguishment time and rely on the reduction of oxygen concentration. The above tests are not directly related to highway tunnels. Many other tests were conducted and it was found in most cases that the fire was never fully extinguished.

Conclusions
Below is a list of conclusions drawn from the tests:

♦ Water spray systems can not be relied on to suppress or extinguish low flash point fuel spills like those that are to occur in tunnels, unless a high discharge density is available. Also the obvious risk with water is the spread of flammable substances.

♦ A foam-water mixture was more effective against flammable liquid spills and a reduce discharge density was possible compare to a water only system.

♦ Foam-water discharge density three to four times higher is required to suppress freight truck fires.

♦ Well ventilated tunnels will affect the performance of water mist systems. A film-forming foam additive to the water will increase effectiveness against flammable liquid. There is also a need to research and carry out more tests for the use of water mist systems in the protection of tunnels.

♦ The system should be of an open deluge type, activated by a separate detection system set with a delay for determination of a false alarm.

The duration of water supply and quantity of water and/or foam concentration should be based on the maximum expected fire duration times. This should also incorporate some safety factors.

- Sprinkler systems in the Betuweroute Tunnels

The Betuweroute project has resulted in the investigation into the possibilities offered by sprinkler systems for fire safety in tunnels and reducing fire resistance tunnel cladding and other civil engineering consequences.

Extensive research and testing was conducted where a number of results were obtained. In relation to sprinkler effectiveness in structure protection without cladding protection, it was found that a flow rate of 10 litres/minute/m² (water and AFFF) resulted in no spalling and that the temperature at the concrete surface (2mm depth) was below 100 °C. A minimal reduction in flow rate generated a rapid increase in temperature and the occurrence of spalling.

8.0 SMOKE MANAGEMENT

8.1 Background Statement:
Smoke management provisions are installed in tunnels to limit the impact of smoke and heat, generated by a vehicle fire.

Smoke management provisions, which have been used in tunnels, include:

- The use of “horizontal jet fans” which generate a longitudinal air velocity in the tunnel to cool and dilute smoke and transport it away from the fire.
- The use of strategically located mechanically assisted or buoyancy driven smoke extract shafts or longitudinal exhaust ducts to remove the products of combustion.
- The use of fresh air to pressurise exit-ways and safe havens or to supplement smoke extract systems via longitudinal supply air ducts.
- A combination of the above systems where a complimentary effect is the outcome.

8.2 Performance Requirements:
A smoke management system shall be designed to minimise the impact of smoke upon occupants:

- Evacuating the tunnel.
- Trapped in vehicles within the tunnel.
- Remote from the fire.
• Working in the tunnel at time of emergency and after.

In the context of these objectives,
• Emergency services personnel are considered as occupants.
• Smoke parameters include temperature, radiation, obscuration, and toxicity.

The design of a smoke management system will be influenced by factors including (but not limited to):

1. The length of the tunnel
2. The slope of the tunnel.
3. Type of traffic flow within the tunnel bore, eg heavy, light, intermittent, single flow direction, two directional, or reversible.
4. Safety facilities provided within the tunnel (eg exits and their spacing, fire fighting provisions - automatic or manual).
5. The anticipated fire size (credible case scenario).
7. Dimensions of the tunnel bore,
8. Method of construction (eg cut and cover or bored tunnel).
9. Materials used (fire load, flammability, spread of flame smoke developed)

Based on the hot smoke tests conducted in the Melbourne City Link and the Memorial Tunnel Fire tests a number of observations were recorded:

The kinetic forces of a fire will drive smoke up gradients and initially along the upper surfaces of the tunnel. If unimpeded, smoke will cool and occupy the full bore of the tunnel. During hot smoke tests (up to 2.5MW) such smoke logging has been found to occur within 100 to 150 m of the fire. It is therefore anticipated that conditions local to the fire will initially be tenable, for occupants to escape fire.

To counter the natural smoke flow, the kinetic effects of longitudinal air velocity may be employed and/or the smoke may be extracted at points of flow along the tunnel. In many designs a combination of longitudinal ventilation and exhaust has been used. Jet fans have been employed to dilute and transport smoke to an exhaust location.

When smoke moves up a gradient or along a ceiling, it may layer above vehicles blocked behind the fire vehicle. This is referred to as “back layering”. The system design should address this problem and be capable of preventing such an occurrence wherever possible. An assumption of this philosophy is that the vehicle on fire has created traffic congestion upstream the fire location with traffic downstream the location being able to evacuate via the exit portal.

When analysing the possible scenarios, which may occur in a tunnel, it becomes apparent that there is no simple solution. It would be very complicated (and expensive) to design a system which could automatically handle all reasonable worst case scenarios.

In practice a heavy reliance will be placed upon the tunnel operator to manage the smoke system during the time taken by the emergency services to arrive, assess the situation and set in place intervention activities and most importantly initiate evacuation procedures immediately. This
requires operator knowledge of the tunnel systems, their capabilities, the location of the fire and knowledge of fire and smoke behaviour. Procedures and operator training will form an essential part of the smoke management system.

Most smoke management systems rely upon the tunnel operator manually operating some or all system components. Operator action is usually determined by feedback from other tunnel safety and security systems such as:

- CCTV used to locate the fire or alarm due to vision obscuration caused by smoke.
- Vehicle motion detectors indicating traffic stoppages and or congestion in the tunnel
- Air velocity and direction sensors within the tunnel
- Pollution sensors within the tunnel.
- Fire or smoke detectors.
- Manual call points and emergency phones.
- Alarms indicating fire protection equipment is being operated in the tunnel.

8.3 **Environmental considerations:**

The discharge of smoke and day to day pollutants from tunnels is of concern to Environmental Protection Agency (EPA). Whilst it may seem reasonable to discharge effluent from the tunnel portal, or from the top of a shaft, an environmental impact study may preclude such a solution.

A pollution management system is synonymous with a smoke management system, the impact of day to day environmental requirements, upon the operation of the emergency system, needs to be assessed. For example it may be impractical to pass the fire gasses through a scrubbing system used for day to day pollution control. A bypass system used for emergencies may be required.

8.4 **Conclusion:**

Various means of smoke management strategies exist and the system selected will be based on the characteristics of the tunnel, economic issues and, but not limited to, the issues raised above.

In any case, the main criteria for smoke management is to provide tenable conditions within the tunnel for the time required by motorists to evacuate to a safe area. The smoke management system should also provide suitable conditions for emergency services to enter the tunnel, assist with the evacuation and rescue of motorists and to initiate fire fighting strategies to extinguish the fire.

Practical testing ie hot smoke testing or real fire tests, should form part of the commissioning of such smoke management systems.

9.0 **COMMUNICATIONS**

9.1 **Background Statement:**

Communication facilities are installed within tunnels for the purpose of both internal and external information sharing. Due to the complex nature of tunnels and various users and operators, communications facilities are of paramount importance.
Tunnel communications bring together many other facilities such as information from the motorists, smoke/fire detection systems, traffic incident detection systems back to the tunnel operator and liaison between emergency personnel and/or tunnel users with tunnel operators.

9.2 Performance Requirements:
Communication facilities within a tunnel must be provided with a high level of reliability and redundancy. In an emergency, the communications facilities will be the only link between people within the tunnel and those people outside the tunnel. As a result the communications infrastructure must be installed within a tunnel in a manner that would result in the continued operation of the system.

Other issues to consider are dedicated systems for various purposes. In an emergency, the communication systems may become congested with motorists, emergency personnel and tunnel operators. As a result the following systems, as a minimum, are recommended:

- Motorist emergency telephone system
- Fire services telephone system
- Dedicated Hardwired Telephone Circuits (DHTC) for Police, Fire and Ambulance.
- Emergency services radio communications rebroadcasting
- AM/FM radio rebroadcasting facilities
- Mobile phone rebroadcasting facilities

Sufficient communication points at various points through the tunnel should be considered. Based on International guidelines and Australia’s experience, telephone points are provided at intervals between 50m and 500m. It is recommended that these communication points are installed at fire service (hydrant, extinguisher etc) points, along with appropriate signage and identification.

Communication facilities are also recommended to be installed within egress routes, and safe haven areas so that motorists may be able to communicate with emergency services personnel and tunnel operators (and vice versa).

As an example of fire brigade communication facilities, the following has been installed within Melbourne’s Citylink and Sydney’s Harbour Tunnels:

- Fire Telephone System (FTS), throughout the tunnels, at DHTC points and at the control room.
- FTS points and handsets are located within fire cabinets and identified by red chequered bands.
- System has a conference facility for up to 3 handsets. Instructions on the use of the facility is contained within the cabinet.
- DHTC Communication System – a pre-wired non-active system that interconnects all fire cabinets and remote DHTC points. These points are located at the same cabinets containing the FTS for use by Fire, Police and Ambulance Services.
- Remote DHTC points are located at the tunnel control room, portal entry and exit points.

10.0 EMERGENCY MANAGEMENT

10.1 Introduction
Tunnels pose particular problems in combating emergencies; the recent incidents in the Tauern and the Mont Blanc tunnels have highlighted the consequences of not incorporating appropriate fire and emergency management into tunnel procedures.
10.2 Fire Service involvement

The early involvement of tunnel operators and the fire services in the design of the tunnel and the provision of fire and life safety facilities will ensure that the final structure will comply with accepted building requirements or engineered principles. This early involvement allows the incorporation of design concepts based on what is considered by fire services as best practice from local national and international experience.

The development of tunnel design with tunnel emergency operational procedures and strategies is of paramount importance. This was highlighted extensively during the proceedings of the Tunnel Management International 2000 Conference, Sydney in 2000.

10.3 Pre-incident Emergency Incident Planning

Undoubtedly one of the most important exercises in pre-planning for an emergency is to prepare and document an Incident Management Plan (IMP), specifically for the tunnel and its approaches, that incorporates the roles and responsibilities of all agencies that may have a part in combating any emergency incident.

To ensure safe operation of the tunnel, the IMP should be prepared by the operators of the tunnel in close collaboration with all the emergency agencies and principal user groups. This representation is best achieved through the establishment of an Emergency Management Committee.

The Incident Management Plan should be clear, concise and as brief as possible and identify the roles and responsibilities of all members of the agency staff in the event of an emergency. Specifically it should identify who does what, when, where and under what authority.

The wide variation in local factors and tunnel characteristics mean that each contingency plan must be tailored to fit specific circumstances. Existing agency Standard Operating Procedures may need to be revised/adapted or new ones developed. The following guidance notes should therefore be seen as general indicators of a range of planning considerations which tunnel operators and brigades may wish to take into account whilst preparing or reviewing their local plans.

Development and detailed documentation of an IMP to cover all emergency situations needs to include the following:

- Identification of all potential incidents and the possible size and complexity based on the type of vehicle and the type of load allowed in the tunnel.
- Establishment of clear emergency management hierarchy in accord with local arrangements, methods of activation and person responsibilities
- Incorporation of the recommendations of principal user groups, ie
  - Tunnel Operators
  - Road transit authority
  - Rail authority
  - Public transport authority
  - Commercial transport groups
  - Environmental Protection Agency
  - Disability Group

- Identification of roles and responsibilities of all tunnel management staff in an emergency.
- Identify special training need for tunnel operating staff
- Development of standard operational procedures by the emergency combat organisations integrating the tunnel emergency procedures.
- Identification with integration of links to local authority emergency sub-plans and state/territory emergency management arrangements.
- Management of maintenance procedures and contractors.
- Acknowledgment and documentation of fire safety and OH&S issues in repairs and maintenance procedures.

10.4 Testing the plan

Regular scenario and practical exercises involving tunnel management and all response agencies need to be carried out at frequent intervals to test individual parts of the management plan and major exercises to test the integration of the plan into response agency procedures.

10.5 Resource determination

Any special resources required for the management and combat of incidents need to be identified and located either within the tunnel precincts or carried on emergency vehicles that are included in the first and backup response.

Resource identification, allocation and location will depend on the circumstances surrounding the tunnel design, size and use and should be identified very early in the design phase.

As an example, in situations where deep penetration is necessary, beyond the point where breathing apparatus wearers may be able to exit to safe air on foot within the limits of the set being worn, a "back up" supply of air may be necessary.

The establishment of safe havens may need to be considered.

10.6 Tunnel Operations Control Room.

In most cases, tunnels will usually be managed by tunnel operators located in Tunnel Operations Control Rooms (TOCR). TOCRs are the nerve system of tunnel management and contain all the communication linkages, including visual screens, for the tunnel. As a result it is recommended that tunnels constructed also include the provisions for a dedicated control centre be set up for the tunnel's day to day operational staff. Fire Brigades should become familiar with this control setup and request that a fire brigade control point be established within the room with all necessary communications and incident control equipment and requirements be provided.

The following may be requested:

- State Emergency Management Plan
- Emergency Services incident room
- DHTC facilities
- Coordination Centre
- Emergency services position within main control room
- Direct line connection with tunnel emergency telephone systems

The provision of a TOCR is deemed necessary so as to provide attending emergency agencies with an area that enables the ability to direct strategies required during a major incident. Facilities should be designed to enable emergency service agencies to carry out functions independent of each other. As such the following equipment is required:

- Exchange telephone points, one per agency as determined (with handsets made available for use when required).
The ability to monitor emergency radio broadcasts.
Facsimile exchange line connection (with a facsimile machine made available for use when required).
Whiteboards (2) and pinboard (approximately 2m x 1m).
Tactical fire plans
Visibility between the emergency service incident room and main control room.

The IMP should identify the existence of the TOCR. In addition the plan must clearly identify the function and responsibilities of the TOCR including its staff and should detail the following:

- The location
- Detailed information of the resources provided at the TOCR,
  - Instructions on the operation of the resources
- The staffing arrangements,
  - Availability, duties, responsibilities, identification (Tabards)
- Liaison officers
- Operational procedures for all installed emergency facilities
- Copies of all emergency management plans.
- Copies of any progressive close down procedures
- Communication plans and emergency procedures
  - Emergency telephone arrangements
  - Emergency radio arrangements
- Fire Service, Police and Ambulance response procedures
- Building plans
- Emergency telephone and contact lists
- Pre-incident response/standby arrangements
- Evacuation procedures
- Normal tunnel operational procedures for minor incidents

Tactical information to be available to local fire stations and emergency services communications centres as determined by the responding Fire Services.

- Building plans
- Emergency telephone and contact lists
- Fire Service operational procedures
- Tunnel access and egress points
- Pre-incident response/standby arrangements
  - Contact points
  - Assembly points
- Evacuation procedures

10.7 Evacuation Plan
The evacuation plan should be prepared and documented in consultation with the fire services, detailing:

- The level and frequency of training required by the management staff
- The level of compliance with Australian Standards.
- Identification of responsibilities of tunnel management incorporating liaison procedures with all responding agencies.
- The procedures for the operation of communication systems to provide evacuation messages both audible and visual.
- Clear instructions on the method of evacuation and route to exits or areas of refuge.
- Clear signage indicating exits or areas of refuge.
- Management of members of the public at evacuation points or within refuges.
- Liaison procedures between responding agencies and management staff.

**10.8 Media and Information Management**

The IMP must identify appropriate media liaison procedures, with nominated and trained staff to manage the media and the liaison function with government representatives, to:

- Ensure the safety of the public and responding personnel
- Provide informative messages through radio and television on
  - Road closures
  - Alternative routes
  - Emergency transport arrangements

- Utilise the media both as an information source and for information dissemination, providing informative messages on the incident itself on such items as:
  - How the incident is being handled
  - Type of incident
  - Number of organisations, personnel, appliances etc
- Fulfil the media accountability expectations of the public
  - Build and maintain public confidence in the agencies
  - Provide the information and avoid speculation on the incident.
  - Create a cooperative approach with the media
- Coordinate public statements
  - Clearance through official channels for possible sensitive information
  - One point of contact for all media releases.
- Organise media presentations
  - Use of credible spokesperson, usually senior operational staff member

Any major incident in a road tunnel, particularly one that is located in a large city, will immediately attract the attention of members of all political parties. It is essential that appropriate media liaison procedures are in place to provide detailed information to the appropriate responsible minister and that the sensitivity of information management at this level is recognised.

**10.9 Liaison procedures**

Any organisation that has an involvement with the tunnel, responsible for any part of its operation, involved in maintenance or is providing resources, needs to be kept informed of the progress of the incident and the involvement of their staff.
Liaison officers need to be established to deal with outside agencies either seeking or providing information and to field requests from the general public.

10.10 Command and Control

A strict command and control structure is important at tunnel fires, given that development and incident progression cannot always be easily or reliably predicted and the added logistical difficulties of managing fire operations in an underground environment. The nomination of safety officers is very important and they should pay particular attention to the possibility of heat stress and ensure sufficient resources for fire fighting rehabilitation.

In areas where different combat agencies are responsible for different incidents it is essential that the responsibility for command, control and coordination is established before the tunnel becomes operational.

As an example, in some states the responsibility for road accident rescue lies with other than fire services, therefore the combat responsibility must be identified prior to the incident.

In protracted and deep seated tunnel incidents proper control must be maintained on access to the tunnel and detailed personnel records must be kept at the entry control.

The incident management procedures must follow clear guidelines that are understood and accepted by all agencies. Most fire services have incorporated the ICS system into their incident management protocols and this system needs to be integrated into the overall command and control procedures to ensure an integrated approach to overall incident management.

According to state arrangements, the separation or combining of command, control and coordination functions at a major incident will differ. It is essential that in the pre-planning stage, all the responsibilities are identified and documented.

10.11 Main Control/Mobile Communication Points

In addition to communication points provided within the tunnel, the emergency services must be provided with an area/s that can function as a main control point from where the tactical aspects of the incident can be managed.

Ideally a location should be identified and fitted out with suitable equipment similar to a fire control room. An area close to the tunnel entrance is the most favoured position. The following equipment is required:

- Dedicated Hard Wired communication points – all emergency services
- CCTV relay
- Hard Standing for Command Units/Liaison Officers
- Direct communication links with Tunnel Operations Control Room.

11.0 EGRESS

11.1 Background Statement:

Egress provisions are installed within tunnels to provide a means by which occupants within the tunnel are able to evacuate the tunnel or are able to move to a location where they will be safe until they are rescued. Egress provisions are also utilised in emergencies by emergency service teams, which need to enter the tunnel to carry out emergency and rescue works.
Basically, in short tunnels the portals may be considered adequate as emergency exits, however in longer tunnels the escape routes should be designed in relation to the type of traffic and the ventilation system, installed within the tunnel.

It is not possible to provide general recommendation for the distance between egress points and such details should be developed for each individual case after consideration of the conditions within the tunnel.

Means of egress or refuge options that have been utilised tunnels include:
- Cross connections leading to the open or to adjacent tunnel.
- Cross connection into pedestrian egress tunnels
- Refuges, especially equipped with clean air, communications and water facilities
- Turning galleries for vehicles.
- Escape stairs

11.2 **Performance Statement:**

Required exit points depend on a number of factors such as the types and volumes of vehicles and the ventilation ad smoke management systems within the tunnel. The aim of egress points is to provide tunnel users a point of egress or safety from adverse conditions within the tunnel. Occupants must be provided with a means by which they can escape to a place of safety prior to smoke reducing visibility or creating untenable conditions.

In determining the required safe egress points for a particular tunnel, the following critical issues need to be identified and addressed:

1. Tunnel traffic densities.
2. Extent of smoke spread through the tunnel under various airflows.
3. Operation of the ventilation system under fire mode.
4. Activation sequence of the smoke control system.
5. Evacuation procedures – installed communication, brigade response times.
6. Tunnel operating procedures; ie timing issues associated with actioning suppression procedures.
7. Motorist characteristics (including for those who are disabled etc)
8. Motorist reaction time.
9. Walking speeds – stairs and corridor cross widths
10. Radiation effects on evacuating motorists.
11. Queuing times encountered at egress access points.
12. Pressurisation of egress paths and refuges in order to keep such areas tenable.

Other considerations include:
- Bi-directional and unidirectional should be evaluated differently.
- Use of cross passages (occupant movement from one tunnel to another) will require that traffic in adjacent tunnel be stopped to avoid endangering occupants who are evacuating from the fire-affected tunnel.
In low traffic tunnels, layby for vehicles may be provided allowing cars to do a u-turn. This is not recommended for tunnels with heavy traffic densities.

European guidelines recommend that escape corridors for tunnels in cities, which have high traffic densities, should be installed at regular intervals. Intervals of 100-200 metres in such tunnels are recommended\(^2\).

Refuges are not preferred, however if they are the only means of providing a safe place to motorists in the event of an incident, they should be equipped with separate fresh air supply and an emergency telephone service connection to the operations and control building. They should be fire and smoke rated. They should be designed to hold the number of people expected between each egress/refuge point.

Signage to international standards is important, however also needs to be suitable for tunnels. Signage should be connected to an uninterruptible electrical power source. As well as signage at egress points, low level lighting should be provided. Location and visibility out of the smoke layer is imperative.

Evacuation systems should always be kept illuminated, such that tunnel users will be familiar with the evacuation routes and points.

Public education should be in place at all times. Ongoing educational, advice and advertising campaigns should provide details to tunnel users relating to emergency procedures, egress voice announcements etc.

Additional means of communication such as variable messages signs, rebroadcasting facilities etc should be integrated as part of the overall evacuation strategy.

A separate egress tunnel should be provided in tunnels, particularly within bi-directional tunnels or tunnels in which adjacent tunnel cannot be used for escape purposes. For unidirectional tunnels, escape to adjoining road tunnel can be considered, however traffic management of the adjoining tunnel is required to maintain the safety of evacuating motorists.

Egress provisions and management plans should also include for those with disabilities.

### 12.0 FIRE SAFETY TESTING & COMMISSIONING

The commissioning of a tunnel’s safety systems is dictated by the nature of the systems installed in the tunnel. It is usual that all systems would be individually commissioned and then commissioned in a way that would simulate the relevant scenarios and sequence of events that would be expected to take place in an ‘incident’. In other words the interfacing of the systems needs to be addressed to demonstrate that they are all working together and talking to each other.

A comprehensive commissioning process needs to be designed so that all likely and some unlikely combinations of events are examined. All too often system failure arises because a specific combination of events was not envisaged but when it does occur the systems cannot cope because they have not been programmed accordingly.

Most major disasters can be attributed to a sequence of malfunctions that were not envisaged.

Commissioning includes not only the operation of the individual systems, but also the performance of the smoke management systems and associated operating systems. Hot-smoke tests can demonstrate the performance and interaction between individual systems. In addition, these tests can be used for training exercises for tunnel operators and emergency services personnel and an opportunity to operate the tunnel in emergency situations; smoke backlayering, effect of suppression systems, evacuation, access for fire fighting, impact of smoke issuing from tunnel and the interfacing of other systems.

Systems, which are utilised as an interface with occupants, shall also be tested. Evacuation drills, performance of information delivery and occupant awareness should also be monitored, tested and updated throughout the life of the tunnel.
12.1  **Hot-smoke testing and its applicability to tunnels**

The CSIRO and the South Australian Metropolitan Fire Services (SAMFS) developed hot-smoke tests in the early 1990's. At that time the smoke tests were a means of verifying smoke modelling predictions for both natural and mechanically ventilated parts of buildings, particularly atria. In addition a large amount of scientific data was gathered by instrumentation installed at the hot-smoke tests.

In the course of carrying out these smoke tests not only were modelling predictions verified and models improved, but a surprising number of defects were identified in the systems being tested.

In 1991-1992 a series of experiments (the so-called Deeds Road tests [1]) was devised and carried out by SAMFS and Adelaide University with assistance by the CSIRO. These experiments advanced the available knowledge of hot-smoke test fires and helped to standardise hot-smoke test methods. The progress of fire engineering eventually saw the advent of an Australian Standard for Hot-smoke tests, the current edition being AS4391 (1999).

It should be remembered that a hot-smoke test is a simulation of the design fire and very rarely is it possible to have a test fire intensity equal to the design fire intensity. Additional considerations in tunnel hot-smoke tests are the tunnel air velocity, and the need to simulate the effect of traffic on smoke movement.

It should be noted that hot smoke tests have not been designed and are not suitable to be used to check the capacity of the system, but rather to demonstrate and confirm operation and interface with other installed systems.

If the need is to test the capacity of the smoke control system, a real fire test utilising fire loads consistent with the tunnel is recommended. The only problem with such tests is the potential to damage the portion of tunnel used for the testing and that each test cannot be reproduced, hence comparisons cannot be made.

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### 13.0 OTHER ISSUES

13.1  **Fire Fighting Equipment**

It is recommended that hydrants, hosereels and extinguishers are strategically located within the tunnel and in associated buildings. Ideally hydrant and hosereel locations should be provided at egress/entry points and throughout the length of the tunnel. Extinguishers should also be provided and accessible for motorists as well as staff and emergency services personnel.

Such equipment is provided in the Melbourne City Link tunnels and similar provisions are provided within the Sydney Harbour Tunnel:

**Hose Reels:** Located every 60m within the tunnels with an equipment niche in the tunnel wall.

**Hydrants:** Unequipped hydrants with fittings are located in each equipment niche at 60 m intervals.

**Extinguishers:** Dry chemical extinguishers are located within each equipment niche in the tunnel and CO2 extinguishers adjacent to all electrical switchboards, control panels etc.

Such equipment should be located within the tunnel, in cabinets and easily visible and accessible by motorists and emergency services. Cabinets should be designed to be clearly seen via CCTV by tunnel operators and each cabinet should be identifiable by signage or a numbering system. The system employed should identify the cabinet location throughout the tunnel and in relation to portal entry/exit points and egress points within the tunnel.
13.2 Community Education

It is very important to establish communication between tunnel operators, emergency services and the public on the use of tunnels, emergency procedures, and tunnel familiarisation. It is recommended that a community education program be set up and implemented prior to the opening of the tunnels and an ongoing program be established once tunnels have been opened for public use.

13.3 Fire Safety System Maintenance

In terms of the ongoing management of tunnel maintenance of the fire safety systems, an appropriate maintenance schedule and strategy is recommended.

Fire Brigades must remain involved in the ongoing maintenance and review of procedures for emergency response to tunnel emergencies and liaison with tunnel operators and control rooms.

Fire Brigades should also obtain a list of all fire safety systems and procedures, maintenance schedules and on a regular basis and confirm that such systems have been serviced and remain fully operational.

13.4 Fire Resistance

The fire resistance of a structure can be defined as the time from which the fire starts to the time when the structure can no longer serve its purpose, due to unacceptable deformation or collapse.

In the event of a fire within the tunnel, the structure and safety equipment should not burn and produce large amounts of toxic gases and smoke. The tunnel structure must not collapse and safety equipment should continue to operate while fire fighting and evacuation is taking place.
13.4.1 Structural Fire Resistance

The main objectives for fire resistance of tunnel structures is to provide:

- Time for evacuation of users
- Time for rescue and fire fighting operations

These general objectives can relate to requirements for an acceptable time before structural failure depending on the consequence. The consequence of a tunnel fail will depend on the nature of the tunnel, i.e., length, width, traffic flow direction, etc. The larger the consequence the higher the requirements.

The following two consequences apply to all tunnels:

- Failure to part of the tunnel must not transfer stress to other parts causing them to collapse and transfer stress to other parts and so on.
- Local collapse should not cut off any vital equipment in the tunnel, such as electrical, mechanical, communication and fire systems.

There are many types of materials used to construct the tunnel structure. These include rock lining, shotcrete, prestressing, and the most common, reinforced concrete. All these materials involve different precautions for fire safety.

Reinforced concrete, when subjected to rapid temperature change, will spall. Spalling may begin to occur at temperatures of less than 200°C or during fire suppression where water causes a rapid cooling effect of the structure. Spalling concrete may be dangerous to the people within the area, especially fire fighters and as such a major safety consideration.

13.4.2 Safety Equipment Resistance

Attention should not only be paid to protecting the supporting structure, but also to the safety equipment and emergency services in the tunnel. Consideration should be given to emergency doors, emergency recesses, communication systems, ventilation systems and other equipment located between two tunnel tubes, the tunnel and the escape route or located on the walls or ceiling of the tunnel. Fire safety equipment shall be protected from vehicular or accident damage.

13.5 Water Supply

The method and quantity will depend upon the firefighting provisions proposed for the tunnel. Nevertheless, a reliable water supply is vital (Australian Standard 2118.1 Grade 1), such that an incident at any section within the tunnel does not delete the supply of water. Consideration should be made for tank storage or mains tapping from both ends of the tunnel, each tapping sufficient to provide the required water quantity. In addition consideration should be made for isolation of parts of the water main for both emergency purposes as well as maintenance purposes. Isolated areas at any one time should be minimised and managed accordingly. The installation of isolation valves throughout the water main is required in order to minimise isolated lengths. This should be designed in accordance with the level of tunnel access provided and the number of deluge zones and hydrants that can be allowed to be isolated at any one time.

Adequate signage to alert fire fighters (or provisions to minimise) of excessive pressures at hydrants locations should also be provided.

13.6 Power Supply

As with water supply, a reliable power supply is vital with multiple redundancies and back-up systems is recommended. Infrastructure throughout the tunnel should be protected from incidents within the tunnel such that an incident within the tunnel cannot destroy power supply. The use of fire rated cabling is also required to be considered for use when infrastructure protection cannot be provided.
13.7 **Environmental Compliance**

A drainage system should be provided in tunnels to collect, store, or discharge, or any combination of these functions, effluent emanating from within the tunnel. In addition to water discharged from the fire protection system and liquids from accidental spills, this effluent also might include water from tunnel cleaning operations and water from incidental seepage.

The drainage collection system should consist of an embedded main drain with grate covered inlets regularly spaced along the curb rather than a continuous open gutter, which could allow spills of hazardous material, such as flammable liquids that could ignite, or propagate along the length of the tunnel. Flame traps should be considered.

Storage tanks and pump stations should be classified for hazard in accordance with the Standards. All motors, starters, controllers should be specified to conform to the intrinsic requirements of the hazard classification.

Storage tanks and pump stations should be monitored for hydrocarbons. Detection of hydrocarbons in the drainage influent should be both a locale and remote alarm.

13.8 **Dangerous Goods**

Tunnels, due to their limited access and egress pose unique fire safety challenges, particularly on firefighting due to both restricted access to the fire site and the confined nature of the tunnel. With the inclusion of dangerous goods within tunnels, fire safety issues are greatly intensified.

Transportation of dangerous goods in tunnels, where permitted, requires the implementation of a management process which is designed and aimed to allow the safe transportation of dangerous goods through tunnels.

In addition the hazards and risks associated with the transportation of dangerous goods should be considered in light of the systems and procedures which may be adopted to mitigate such risks. There will be some forms of dangerous goods in which no single system or procedure may be utilised to handle an incident and therefore these types of dangerous goods may be totally prohibited from the tunnel if an alternative is available or the risk of such an incident is taken and therefore the substance be allowed.

Based on international practices the following common practices may be implemented as part of a management process to allow such transportation:

- Escort of vehicles
- Transport vehicle fitted with amber flashing lights
- Drivers to notify tunnel operators and seek advice
- Prohibition of highly explosive goods/LPG
- The use of designated lanes in tunnels
- Separation distances between vehicles
- Designated times of use

Other issues to consider when managing the transportation of Dangerous Goods through tunnels include:

- Risk assessment
- Design fire size, duration and impact
- Structure
- Detection and suppression
- Communications
- Explosion safe sumps and their capacities
- Drainage and waste disposal, containing vast amounts of water to dilute the substance
- Extinguishing agents
- Ability to provide alternative routes and divert traffic
- Load limits on placarded vehicles
- Hours of operation
- Liaising between parties such as fire brigades, tunnel operators and hauliers, to determine the safest possible transportation procedures
- Roadside control/audit/checks before entering the tunnel
- Restrictions on types of dangerous goods

It should be noted that legislation for the transportation of Dangerous Goods in each State and Territory exists. The relevant Authority should be involved in the decision to allow dangerous goods to be taken through tunnels. In addition the transportation of dangerous goods should be addressed considering both placarded and unplaced levels.

Reference can be made to International practices as presented within PIARC publications. 2, 22

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## 15.0 ABBREVIATIONS AND ACRONYMS

<table>
<thead>
<tr>
<th>Abbreviation</th>
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<tr>
<td>AFAC</td>
<td>Australasian Fire Authorities Council</td>
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<tr>
<td>AFFF</td>
<td>Aqueous Film Forming Foam</td>
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<td>CCTV</td>
<td>Closed Circuit Television</td>
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<td>CFD</td>
<td>Computational Fluid Dynamic</td>
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<td>CSIRO</td>
<td>Commonwealth Scientific Industrial Research Office</td>
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<td>DGV</td>
<td>Dangerous Goods Vehicle</td>
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<td>DHTC</td>
<td>Dedicated Hardwired Telephone Circuits</td>
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<td>Environmental Protection Agencies</td>
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<td>FTS</td>
<td>Fire Telephone System</td>
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<td>HGV</td>
<td>Heavy Goods Vehicle</td>
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<td>IMP</td>
<td>Incident Management Plan</td>
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<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
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<td>NFPA</td>
<td>National Fire Protection Association</td>
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