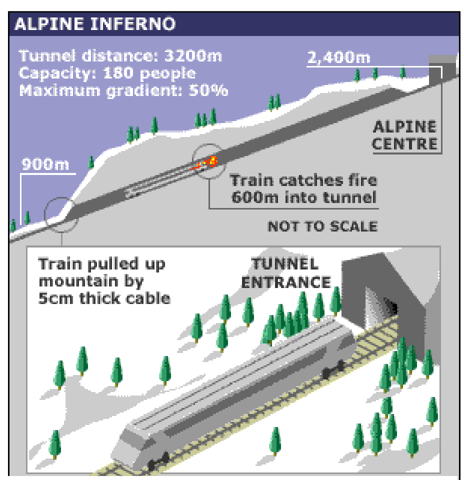
Tunnel Fires - From Zero to Blast Furnace in 60 Seconds

" The differences between ***subterranean*** *environments and other environments are so vast there is no straightforward comparison between them. Communications, egress, ventilation, drainage, water supply and traffic control issues are exacerbated when moved underground or under water". (Pam Weiger, NFPA journal.)*

Mont Blanc is the tallest mountain in Europe. It looks down upon the intersection of three counties, France, Italy and Switzerland, and presented the most formidable barrier to Hannibal and his armies as they struggled with the glaciers and avalanches on their march southward. Today, the famous conqueror could enjoy a leisurely stroll through the heart of the mountain thanks to the eleven kilometer Mont Blanc Tunnel linking France to Italy. However, on March 24th, 1999, this would not have been the case.

On that date, a truck with Belgian registry carrying large quantities of flour and margarine caught fire approximately half way through the 11 km tunnel. In the confined space, the fire quickly reached temperatures exceeding 1000 º Celsius, (1800º F.). Vehicles simply melted. The heat was so intense the cement lining started to shatter and the tunnel began to collapse. The fire raged for three full days before it could be brought under control. Thirty-nine people were killed, 25 trucks including two fire engines were destroyed as were eleven cars. 1200 meters of the concrete lining was destroyed or heavily damaged. The tunnel, an important asset in transportation in that part of Europe, was closed for three years, with an estimated loss of $1.5 million (US) per day.



A tunnel presents its own set of unique characteristics when it comes to a fire emergency, not the least of which is the element of confinement. High temperatures and limited access can make effective response extremely difficult if not impossible. In a tunnel, there is simply no where to run. This was tragically underlined on November 11, 2000 in the Austrian town of Kaprun. A passenger train with 162 people on board was making its way through a 3.2 kilometer tunnel when an errant spark ignited some leaking hydraulic fluid, causing an explosive fire. In this case, the steep tunnel acted like a giant chimney drawing air in from the bottom and spewing toxic smoke and gases upwards. The train instantly became the funeral pyre for one hundred and fifty travelers. Rescue attempts could not even be considered for three long, agonizing hours.

Extreme temperatures provide their own set of concerns. In May, 1994, the 31-mile tunnel linking Folkstone, England to Coquelles, France popularly referred to as the Chunnel, was opened to rail traffic. Two and a half years later, it was closed as result of a tunnel fire. Fortunately, there was no loss of life and service was interrupted for only 15 days. However, the damage to the concrete lining was extreme. In fact, at the site of the fire, the tunnel lining was completely destroyed, revealing the substrata through which the tunnel had been carved.

Fortunately, the substrata was stable enough to support the tunnel and prevent further collapse, otherwise the incident could have had a much different conclusion. Research carried out at MIT after this fire showed that, "when mature, dried concrete is exposed to extreme heat for long periods of time, the chemical bonds between the water molecules in the concrete break, destroying molecular bridges that bind together the various materials that make up concrete." (*MIT News, April 20, 1999*). A small portion of the exposed concrete actually explodes, peeling off in thin layers like an onion (referred to as spalling). This will continue to happen until the heat is reduced or removed. Fire fighters attacking the Chunnel fire had to be relieved every five to eight minutes because of the heat. At the same time, explosive spalling of the concrete hindered their advance as the concrete dust worsened visibility. The debris rained down on their helmets and formed a treacherous carpet of loose, red-hot rubble.

These circumstances were reflected in the Mont Blanc tunnel disaster a mere 16 months later.

Extreme heat, limited or no access, confined smoke and gases, add up to a recipe for certain disaster. Fortunately decisions based on economics are giving way to life safety considerations in tunnel design. Recently, the World Road Association (referred to as the PIARC) Committee on Road Tunnels studied the issue of fire and smoke control in tunnels and in May of 1999, prioritized their recommendations beginning with saving of lives through user evacuation, followed by improved rescue and fire fighting operations, preventing explosions and limiting tunnel wall damage. *(Industrial Fire Journal, March 2002).*

Fortunately for the passengers on the train involved in the Chunnel fire, many of these considerations had been incorporated into the design of the tunnel. *(see NFPA Report by ED Comeau, 05-09-2002).*

Channel Tunnel in Cross section

The Chunnel is actually a set of three tunnels, two running tunnels each 25 feet in diameter, separated by a service tunnel with a diameter of 16 feet. The service tunnel has 270 cross passages (one every 1,230 feet) to the two running tunnels. The train with the burning freight car had stopped, and passengers in a club car closest to the fire were successfully evacuated into a nearby cross passage.

They were treated for injuries and smoke inhalation by FLOR (First Line of Responders), from the French side. The Supplementary Ventilation System which was designed to control the volume and direction of airflow, was activated and set to draw the air towards to rear of the train which allowed the other passengers to evacuate the remaining cars and escape into the service tunnel. There they where met with medical aid and transport via ambulances to the French side.

Stopping a fire before it has a chance to grow was the intention when an automatic on-board fire suppression system was installed on the entire fleet of freight shuttles. The system is designed to limit the rise of temperature and inhibit the fire spread *(see Aquasys, www.aquasys.at)* using water mist technology. In this system, pure water is reduced to droplets of approximately 90 microns (there are 25 microns in one thousandth of an inch) and delivered by high pressure nozzles. These tiny droplets absorb heat, vapourize and expand to 1600 times the original volume thus cooling the fire and supplanting the oxygen immediately adjacent to it.

Water mist suppression systems installed in tunnels have proven to be very effective in cooling 80-100MW vehicle fires. Unlike sprinkler-type suppression, water mist does not contribute to the spread of petroleum fires and they will reduce the chance of explosions of flammable gasses that may remain in a confined space even after a fire is extinguished. More than 100 water mist systems have been installed in the London underground system where, as is the case in any underground rail system, it is extremely important to reduce the heat load, cool the hot smoke and toxic gasses as well as block the radiant heat to prevent the spread of the fire. *(see* www.hi-fog.com*)*

Jet-type fans move smoke to extraction points

Extraction of smoke and gasses offers its own set of challenges. As expected, in the confined space of a tunnel, smoke, heat and gasses from a just a 20 MW fire (typically a truck fire) travel quickly covering distances of 1,500 to 2,000 feet in two minutes. Ventilation systems must be designed to extricate the hot gases as well as supply fresh air to sustain life. Many factors come into play when designing an extraction system, not the least of which is the natural chimney effect created in a tunnel. An overall gradient of just 2% is sufficient to create a draught that can oppose a ventilation system and inhibit smoke extraction.

Up to now, transverse ventilation (the controlled introduction of fresh air and the extraction of smoke at the ceiling level) has been the method of ventilation in tunnel fires. In the Mont Blanc Tunnel disaster it was noted that the 30 year old transverse system had two control points, one at the French entrance and the other at the Italian end. Neither operator could control the actions of the other, severely limiting the effectiveness of the ventilation system*. (see Pam Weiger, NFPA Update, 11-02-01)*

Experiments in smoke extraction using actual tunnels are pointing out new approaches to tunnel design that can drastically reduce loss of life in a tunnel fire.

In 1995, the obsolete Memorial Tunnel near Charleston, West Virginia was set up as a test centre for ventilation and extraction systems. It was noted that jet fans, similar in appearance to jet turbine engines and installed at regular intervals along the tunnel, can be most effective in single-direction tunnels such that the direction of venting heat and gases is in the direction of the traffic flow. In a bi-directional tunnel, this is not the case.

Memorial Tunnel Entrance

Extraction by means of a ceiling exhaust ducts proved to be the most effective method and accommodated bi-directional traffic flow. In this system, large controlled openings (dampers) as large as 150 sq. ft. and installed it intervals of 300 ft. centres, can easily manage smoke and high temperatures generated in a 20 MW fire, and do so with a ventilation rate of only 100 cfm per lane foot. This is the minimum ventilation rate that was established by ASHRAE (the American Society of Heating, Refrigeration and Air Conditioning Engineers) many years ago, yet was never proven to be appropriate for all situations. The location and spacing of the large dampers could mean that smoke and heat being drawn from the fire to the opening could pass over and around stalled vehicles and their occupants. A variation of this method uses oversized exhaust ports of approximately 30 sq. ft., 30 feet apart, that provide extraction in the immediate vicinity of a fire. The ports fully open when subjected to the heat of a fire, drawing smoke and hot gases into the exhaust duct. It was also determined that there is always sufficient oxygen in a tunnel to support combustion, however the increase in fire intensity due to the influx of fresh air provided by a ventilation system, did not outweigh the benefits of life support.

Hi-Fog® Water Mist suppression system protects escalators, kiosks, passenger areas and tunnels of the Madrid underground transit system.

Tunnel Fire Resistance, i.e. the amount of time between the inception of a fire and the deformation or collapse of the tunnel, is an important calculation when considering the escape of tunnel users and fire fighting operations. A fire resistant material can be added to the concrete shell at the time of construction for a very nominal cost estimated to be a mere 0.1% - 0.5% of the overall capital expenditure. This fire protection material has been applied to the walls and ceiling of the 3.5 km Oserund Tunnel joining Copenhagen to Scania, and will prevent the temperature of the concrete surface from exceeding 380ºC after being exposed to a petroleum fire for more than two hours. This feature used in conjunction with water mist suppression and directional ventilation offers a formidable defense against a tunnel fire catastrophe.

The Mont Blanc tunnel has been upgraded with 116 smoke extractors and 76 new fresh air vents. Vehicles are subjected to heat–sensing scanners before they enter the tunnel, which is now monitored by 120 video cameras. $300 (US) million is being spent to convert sub-floor clean air ducts into personnel escape routes, and 35 airtight shelters with escape routes are being installed in the granite walls. An early detection system consisting of flame detectors and infra-red sensors is also being considered.

If he appeared today, Hannibal and his fearsome horde would be able to invade in safety and comfort.

Dave Duggan, March 2002